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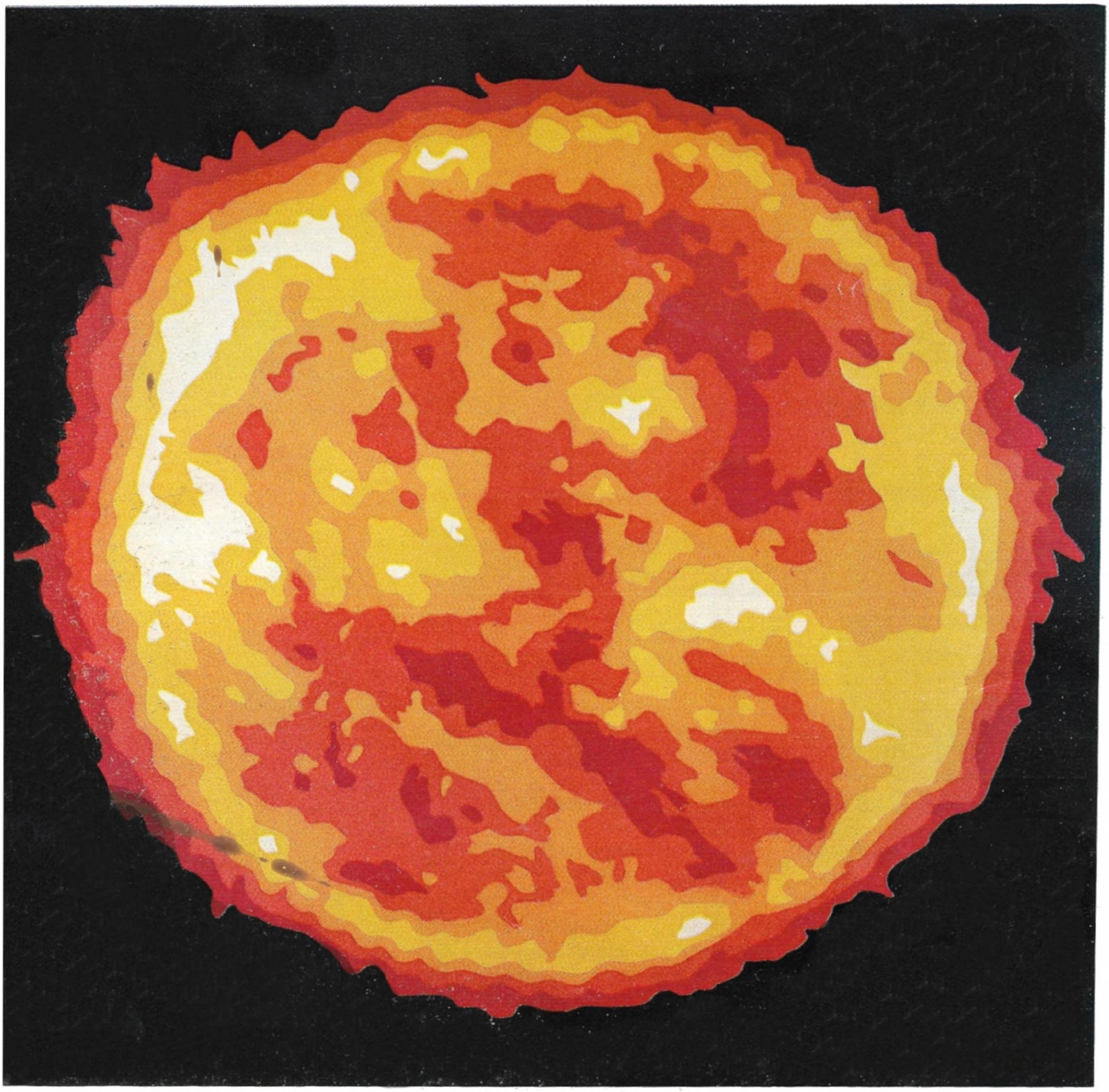

THE SOLAR CORONA

ONE DOLLAR

October 1973

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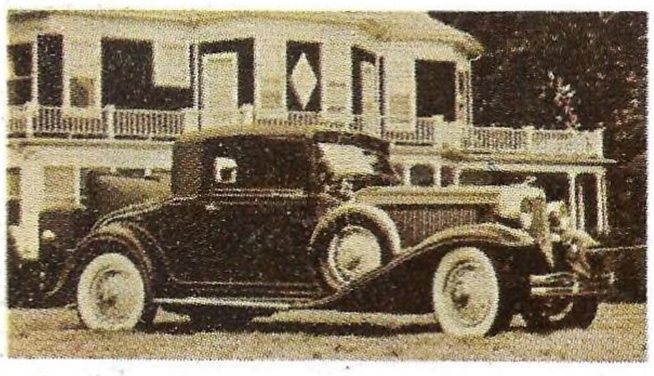

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Tornadoes, Rockets and Sonja Heine

So far, 1973 has been a banner year for tornadoes. By mid-year, more than 750 of these violent storms had swept down on the United States, killing 59 people and causing millions of dollars in property damage. Scientists expect the existing tornado record of 928 (set in 1967) to be easily shattered before the year is over.

Recently, tornado research has received help from an unexpected source — namely, studies made by TRW scientists of flow patterns in the propellant tanks in ICBM missiles. When you pump fuel out of a liquid rocket tank, much the same thing happens as when you pull the stopper out of your bathtub — a radial flow pattern develops (the particles move in spiral paths toward the center) and a vortex appears. To find out how swirling fluids behaved in propellant tanks, TRW scientists made some fundamental studies of the formation and behavior of vortexes. Further research has extended their analyses to the behavior of the large vortical patterns in the atmosphere we know as tornadoes, waterspouts, dust devils, and fire whirls.

A tornado begins with a thermal instability in the atmosphere, e.g., large mass of warm moist air under a layer of cold dry air. Under such conditions, violent updrafts may begin, around which the surrounding air begins to flow radially inward, in a swirling, spiral pattern. As particles get closer to the center of the flow pattern, their velocity increases. Some readers will recall the startling rotational speeds Sonja Heine achieved as she drew her extended arms closer to her body. Particles of air experience this same increase in rotational velocity as they get closer to the center of the system.

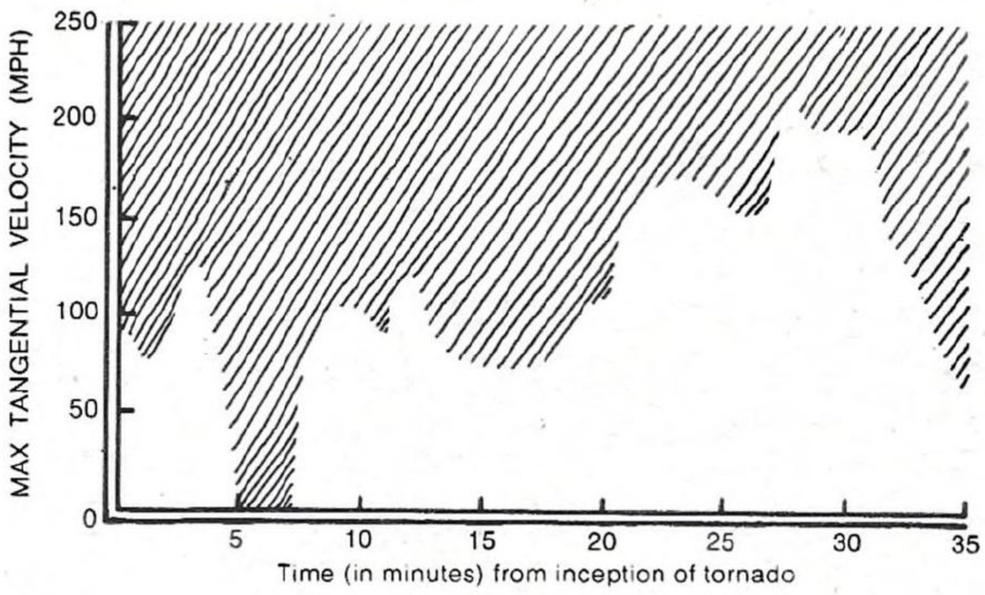
Ordinarily, turbulent diffusion opposes the swirling, and relaxes the disturbance — i.e., friction prevents Sonja from bringing her arms inward. However, in rare circumstances the radial inflow overwhelms turbulent diffusion, and a tornado develops. Actually, in a killer tornado much of the radial inflow is eventually confined to a layer near the ground, because at greater heights the increase of swirling ultimately creates a large centrifugal force that counteracts further radial inflow.

While dust and debris are being swept upward, the funnel of the tornado appears to descend. The latter occurs because the faster the air swirls, the more its temperature drops and the less moisture the air can contain. The resulting condensation of water vapor is seen as the funnel of the tornado, snaking down from the ominous cloud deck. Using these facts, TRW scientists have developed a formula which enables them to calculate the maximum velocity of winds in a tornado.*

TRW scientists have estimated the maximum wind speed in the funnel of a major tornado at around 225 m.p.h. Much of a tornado's destructiveness, however, stems not from the speed of the swirling wind, but from the radically low pressures inside the funnel. As a tornado engulfs a building, air trapped inside the building causes it to explode.

While much remains to be learned about large vortical storms, TRW's work with swirling liquid rocket propellants has lead to an important meteorological understanding of the behavior of destructive rotational storms.

**Maximum velocity, $V = (kgh)^{1/2}$, where h is the altitude of the cloud deck, k the fraction of the distance between cloud and ground the funnel cloud tip has descended, and g the acceleration of gravity.*



Using Weather Bureau data from the tornado of April 2, 1957, TRW scientists calculated the above time-history of estimated maximum wind speeds.

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Established 1845 **SCIENTIFIC AMERICAN** October 1973 Volume 229 Number 4

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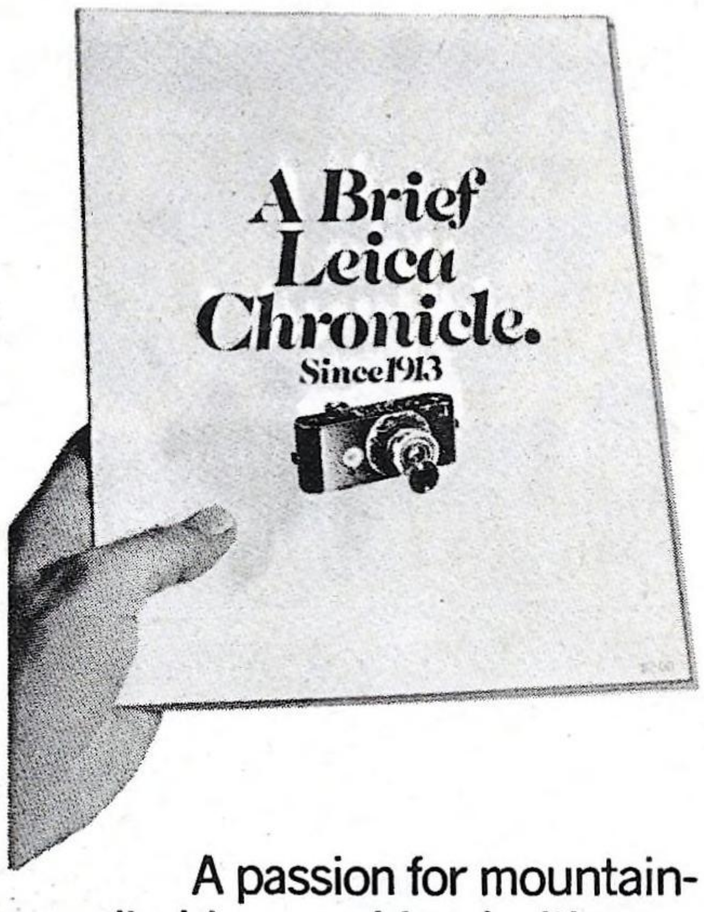

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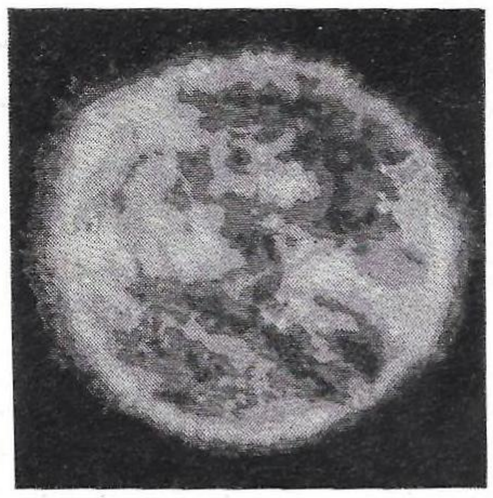

THE COVER

The colorful pattern on the cover is a spectroheliographic diagram of the sun in the extreme ultraviolet region of the spectrum. The diagram was constructed from measurements made by a spectroheliograph put aboard Orbiting Solar Observatory VI by the Harvard College Observatory Solar Satellite Project (see "The Solar Corona," page 68). The instrument isolates a single wavelength in the spectrum of the sun and the inner corona. Here the wavelength is 625 angstroms, the spectral line of magnesium stripped of nine electrons at 1.3 million degrees Kelvin. The deep red regions in the picture are the coolest and the white regions are the hottest. Spectroheliograms made in the spectral lines of elements of higher and higher ionization reveal the structure of hotter and hotter regions of the corona.

THE ILLUSTRATIONS

Cover courtesy of Harvard College Observatory Solar Satellite Project

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SCIENCE/SCOPE

A "man-in-the-loop" RPV strike mission simulator has been built by Hughes in a company-funded research project to evaluate the problems of remotely-piloted vehicles. These include video bandwidth, jamming, and vehicle steering. The man-in-the-loop provides critical target recognition and sensor pointing for weapon delivery and also enables a narrower bandwidth to be used, thus minimizing jamming. The complete system makes use of a TV chain, flying-spot image scanner, digital scan conversion, digital computer, analog converters, hybrid interface equipment, and operator and experimenter control station consoles. It can simulate the critical portion of the RPV strike mission, from the time the vehicle, cruising at low altitude, "pops up" to high altitude to acquire the target, until it delivers the weapon.

A revolutionary reusable module to protect delicate electronic equipment in transit to and from maintenance or calibration facilities is one of a family of packaging, handling, transporting, and storage systems developed by Hughes as a systems approach called ISOPOD™. The module provides a dessicant basket, humidity indicator, relief valves, four-way forklift access, lift/tiedown rings, locking capability, and a 10-year design life. It requires no additional packaging, accommodates a wide variety of shapes, sizes, and weights, and isolates its contents from shock and vibration. Extensive tests and practical use show that the module virtually eliminates damage to equipment.

A high-resolution graphic display system incorporating the Conographic™ curve generator was introduced by Hughes at the recent WESCON show in San Francisco. The Conographic curve generator provides data compression of 10:1 or better as a result of its capability for generating conic curves, circles, and ellipses. Applications include seismic analysis, weather mapping, contour plotting, and computer-aided design and drafting. The new Conographic-12 system uses a Hughes 639 video memory, which provides a video display with 1029-line resolution. The video memory also provides selective erasure and makes it possible to view computer-generated graphics in high ambient light conditions.

Hughes Research Laboratories has two openings in R&D on advanced solid-state devices in the microwave and mm-wave region: 1) Extensive experience and demonstrated achievement in design and application, plus leadership ability. 2) Outstanding experience in fabrication and processing, including epitaxy, photolithography, etc.; this position requires use of advanced electron/ion beam techniques. U.S. citizenship required. Please send your resume to: Mr. A.J. Simone, Hughes Research Laboratories, 3011 S. Malibu Canyon Road, Malibu, CA 90265. An equal opportunity M/F employer.

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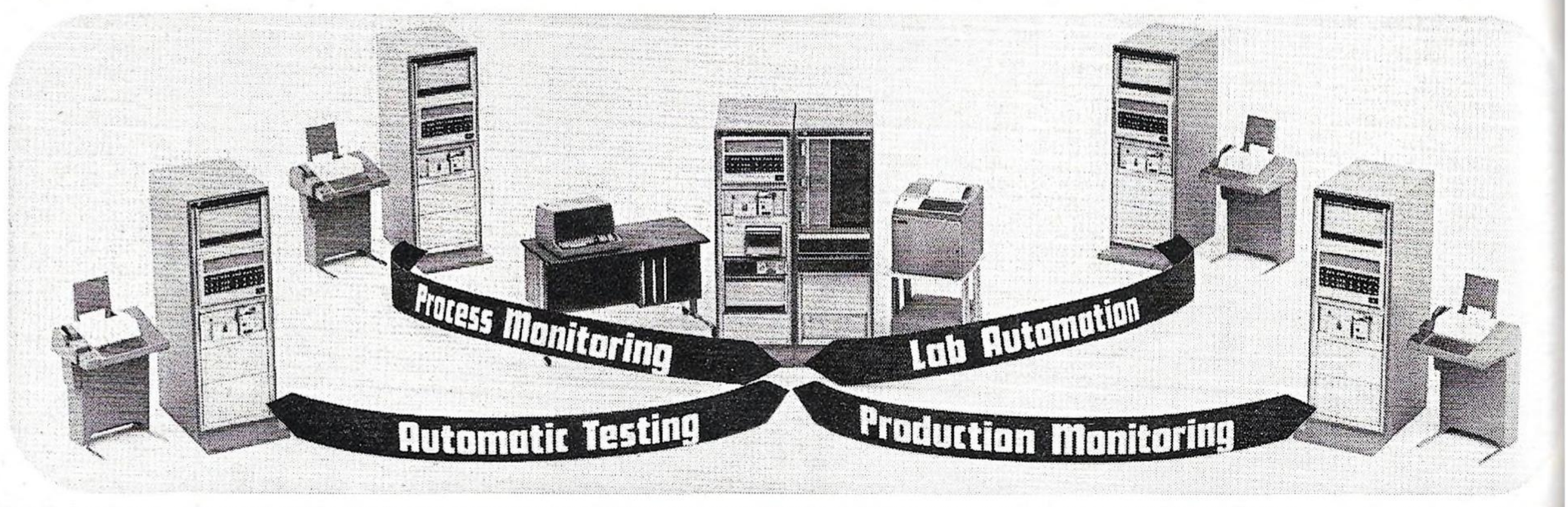
A further level of computer power is also available with HP distributed systems, for the central computer can communicate directly with a host IBM 360/370, enabling HP 2100 networks to be an integral part of a hierarchal information distribution and processing system.

Key to it all are two Distributed Systems Packages: the HP 91701, about $6000 of hardware and software that establish and manage communications between the control 2100 and each satellite 2100 system; and the HP 91780 (about $5000) that performs a similar function for the central 2100 and host IBM computer.

If this idea interests you, ask for literature on Distributed Systems.



Increase surface chemistry data with an HP monochromatized ESCA Spectrometer.

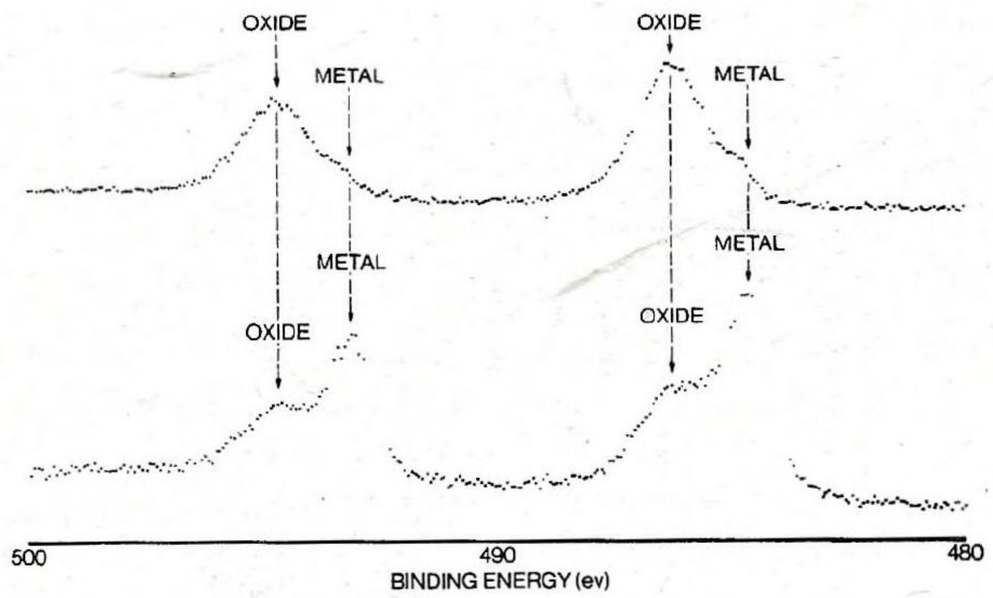
One of the most promising and powerful new analytical techniques, ESCA (Electron Spectroscopy for Chemical Analysis) now provides a chemical characterization of sample surfaces (10-20 angstrom deep). It has a broad range of applications: the effect of sunlight on polymers, the composition and uniformity of deposited thin films, the efficiency of washing processes, the molecular structure of complex organic molecules, and the effect of lubricants on metallic surfaces, as well as many other problems.

An especially important application for ESCA appears to be in characterizing catalysts. Catalysts are essential to the manufacture of materials, yet determining the properties of these compounds and finding methods to evaluate their efficiency are important problems that until recently have defied almost all analytical techniques.

Predicting the performance of fresh catalysts has been equally difficult. ESCA offers hope here; not only can it determine the oxidation states of species at the surface, but it can give information about surface conductivity, an important parameter for characterizing catalyst activity.

Although early investigators have already made important discoveries in surface chemistry and physics with ESCA, they have been unable to realize its full potential because of the design limitations of the first generation of instruments.

In all these spectrometers, the raw X-rays



An example of the kind of surface chemical information ESCA provides is shown in these spectra of tin. In the upper spectrum, tin (3d) ESCA peaks occur from the surface of a copper alloy sample. Mostly tin oxide with a small amount of metal is present. The lower spectrum shows tin (3d) peaks after the sample was surface "cleaned" with argon ion bombardment for five minutes. Note how the results indicate the partial removal of the tin oxide surface layer.

used to excite the sample produced satellite emission lines and a characteristic background that showed up in the ESCA spectrum and confused its interpretation. They were limited by an inability to use and control sample charging effects.

Our 5950A ESCA Spectrometer incorporates a unique spherically-bent quartz crystal monochromator that offers greatly improved performance above limitations of non-monochromatized X-ray photo-electron spectrometers. It allows chemists and physicists to take full advantage of the ESCA technique. System prices start at $125,000 (U.S. only). Ask for further information.

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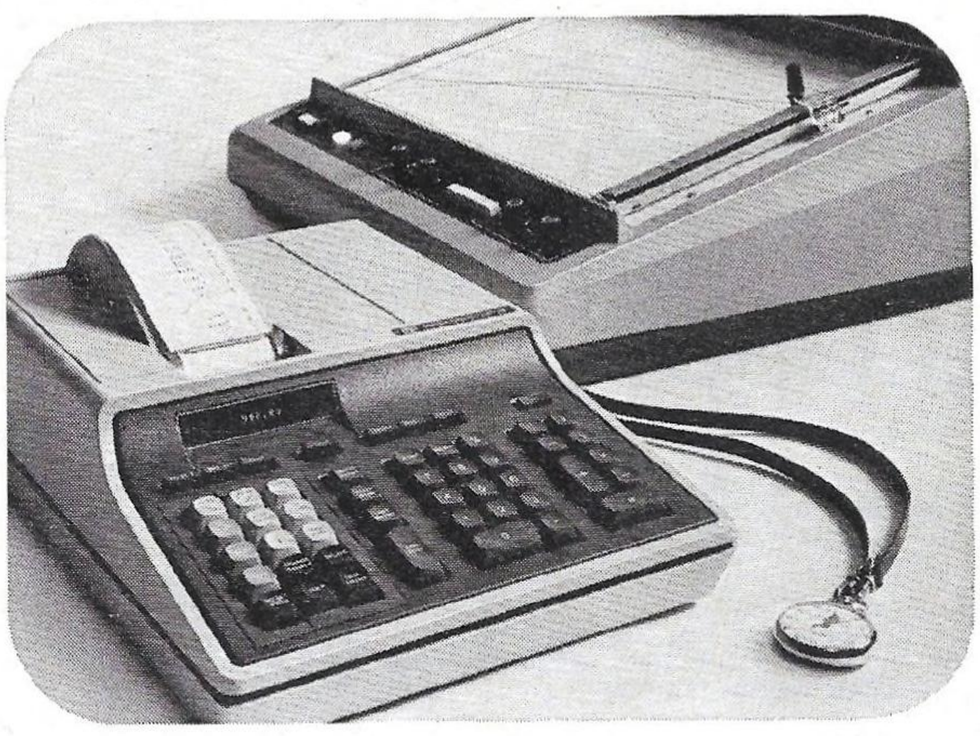

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LETTERS

Sirs:

In the article "An Advice-taking Chess Computer," by Albert L. Zobrist and Frederic R. Carlson, Jr. [SCIENTIFIC AMERICAN, June], mention is made of a £1,000 wager by international master David Levy that no computer-chess program will be able to beat him by 1978. Unless his chess-playing ability deteriorates radically, Levy seems to have a very safe bet.

Back in 1957 Professor H. A. Simon of Carnegie-Mellon University (one of the fathers of "artificial intelligence") made a number of famous predictions of what computers would be able to do within 10 years of that date. One of his predictions (none of the predictions has yet come true) was that a computer program would be chess champion of the world.

Professor Simon has since indicated that he thought then (in 1957) that far more effort would be devoted to problems of this type than has actually been expended on them. I do not know how much effort would be required to produce a chess-playing program by 1978 that can play as well as Levy can play now. There is serious doubt about whether it could be done in that time even if unlimited resources were available. Actually the resources are, and should be, quite limited. The few dozen people spending a few hundred thousand dollars a year that are working on this problem could not *produce* a program that plays at the 2,400 level (my guess as to Levy's chess-federation rating) by 1978 even if they now had some reasonable idea of how to go about it. There is no evidence that such ideas now exist. They are not going to get there by simply pushing the current technology in this area a bit further. It has taken 24 years to get from Claude Shannon's paper to a program that can establish a Class *C* rating. At the current rate of research, even with the much more powerful machines available, it will almost certainly take more than 24 years to get past Class *B*.

Note that best ratings now claimed for computer programs fall in the 1,400–1,600 Class *C* level. Class *B* is 1,600–1,800, Class *A* is 1,800–2,000 and expert is 2,000–2,200. The master level starts at 2,200. As a chess player and a computer scientist, I have been following the work in this area with great interest from the very beginning. Considering the methods now in use or seriously proposed, including those in the very interesting *Scientific American* article, I think that it is excessively optimistic to predict that a computer program will be able to play even at the Class *B* level by 1978.

SAUL ROSEN

Director
Computing Center
Purdue University
Lafayette, Ind.

Sirs:

As a preface, I should like to say that there are serious philosophical problems as to what constitutes "progress" in the field of artificial intelligence. One view, which can be traced back to an early paper by A. M. Turing (*Mind*, October, 1950), sets the goal of producing an intelligence in computers that is indistinguishable from human intelligence, and so it follows that progress toward that goal is measured by using human performance as a yardstick for computer performance. This view is ultimately correct, since the absence of progress would eventually indicate that Turing's goal cannot be achieved. As a working philosophy, however, there are several drawbacks to such an approach. First, no value is placed on understanding the nature of intelligence. Second, no allowance is made for the exploration of possible mechanisms of intelligence without immediate concern for their effectiveness. Our group at the University of Southern California has concentrated its effort on the formulation of mechanisms that would lead to intelligent chess play, and similar efforts are under way at Carnegie-Mellon University and elsewhere. Rosen claims that our ideas will not produce a Class *B* chess player. How can he be sure when we are unsure (but hopeful) and are investing several years of our time to test our ideas?

A previous critic of chess efforts, Hubert Dreyfus, was thrashed by a chess program at the Massachusetts Institute of Technology. Rosen may be setting himself up for the same fate. Although I have not indulged in any predictions or wagers, I feel that his predictions are excessively pessimistic.

ALBERT L. ZOBRIST

Information Sciences Institute
University of Southern California
Marina del Rey, Calif.

Sirs:

May I correct a statement in my article "Public Policy on Fertility Control" [SCIENTIFIC AMERICAN, July]?

On July 1 the Department of Health Education, and Welfare reorganized its Health Services Administration and abolished the National Center for Family Planning Services. As a result administration of what remains of the Federal family-planning effort is now delegated to a new Bureau of Community Health Services that will have a cadre of full-time headquarters specialists working on family planning only one-tenth as large as formerly. The future of the Federal family-planning program is thus even more uncertain now than when the article was written this spring.

FREDERICK S. JAFFE

Director
Center for Family Planning
Development
Technical Assistance Division
of Planned Parenthood–
World Population
New York

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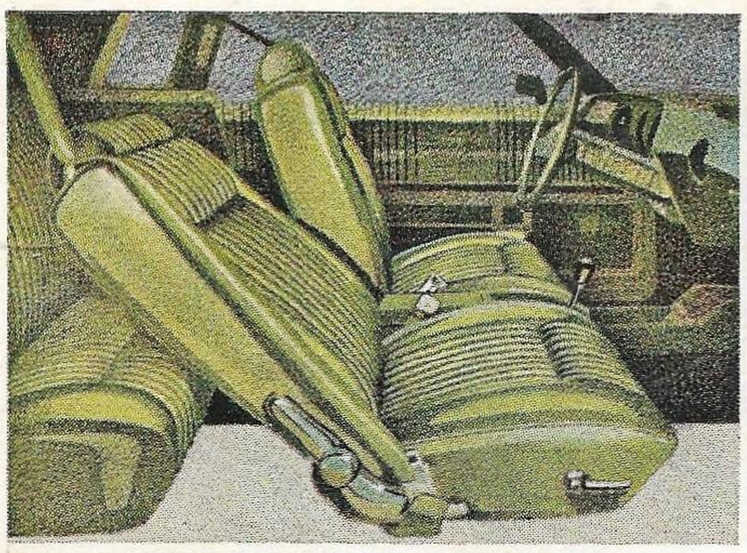

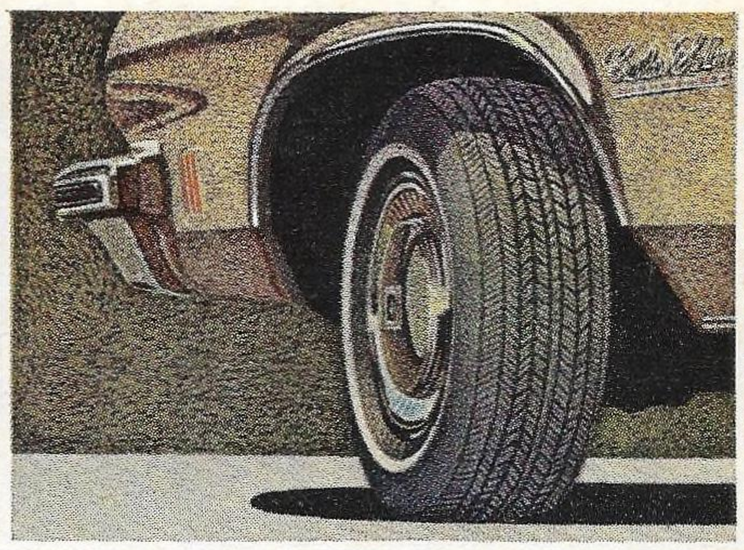

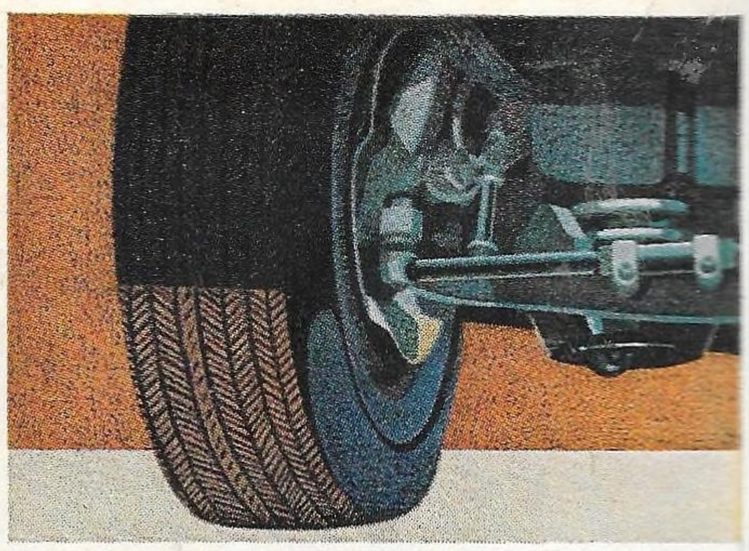

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

OCTOBER, 1923: "The coast-to-coast flight is undoubtedly one of the most dramatic achievements of modern aeronautics. Lieutenants John A. Macready and Oakley G. Kelly of the Army Air Service, leaving Roosevelt Field on Long Island, reached Rockwell Field in San Diego after a nonstop flight of 26 hours 50 minutes, covering an airline distance of 2,600 miles. According to the pilots' own estimate the average speed maintained was 93½ miles per hour. In the initial stages of the flight the plane was greatly overloaded, and an altitude of only 1,500 feet could be maintained over Long Island, New York City and New Jersey. Reaching Indianapolis and Tucumcari in New Mexico, they flew by compass alone. They welcomed the hangars of Rockwell Field with relief, and came down in perfect condition, although neither flyer had slept during the entire trip. The lessons of the flight are most important. Apparently the airplane is now ready for commercial air transportation."

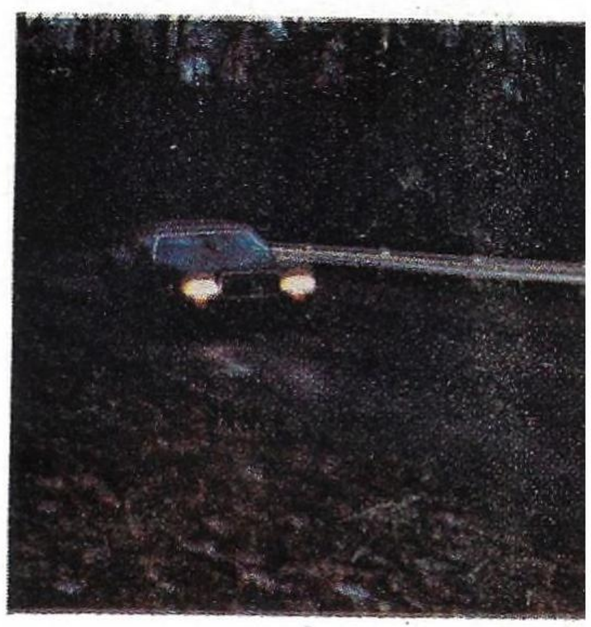
"Last year 14,000 lives were lost in this country in automobile accidents. The present registration shows that there are in the U.S. 12,000,000 vehicles, and the manufacturers estimate that the increase this year will be 3,000,000. The risk to safety lies in the fact that 90 per cent of these vehicles are congested on 10 per cent of our roads. Recommendations to reduce the ghastly slaughter come under four heads: first, to secure good designs for new roads; second, to promote adequate improvement of old roads; third, to insist on reconstruction of existing roads at places that have proved especially dangerous, and last, to improve the location of the center line on dangerous curves and elevations. Curves should be banked as a protection against skidding, and on all curves of more than four degrees the pavement should be widened. Another important recommendation is that a line about four inches in width should be painted in the center of the pavement on curves."

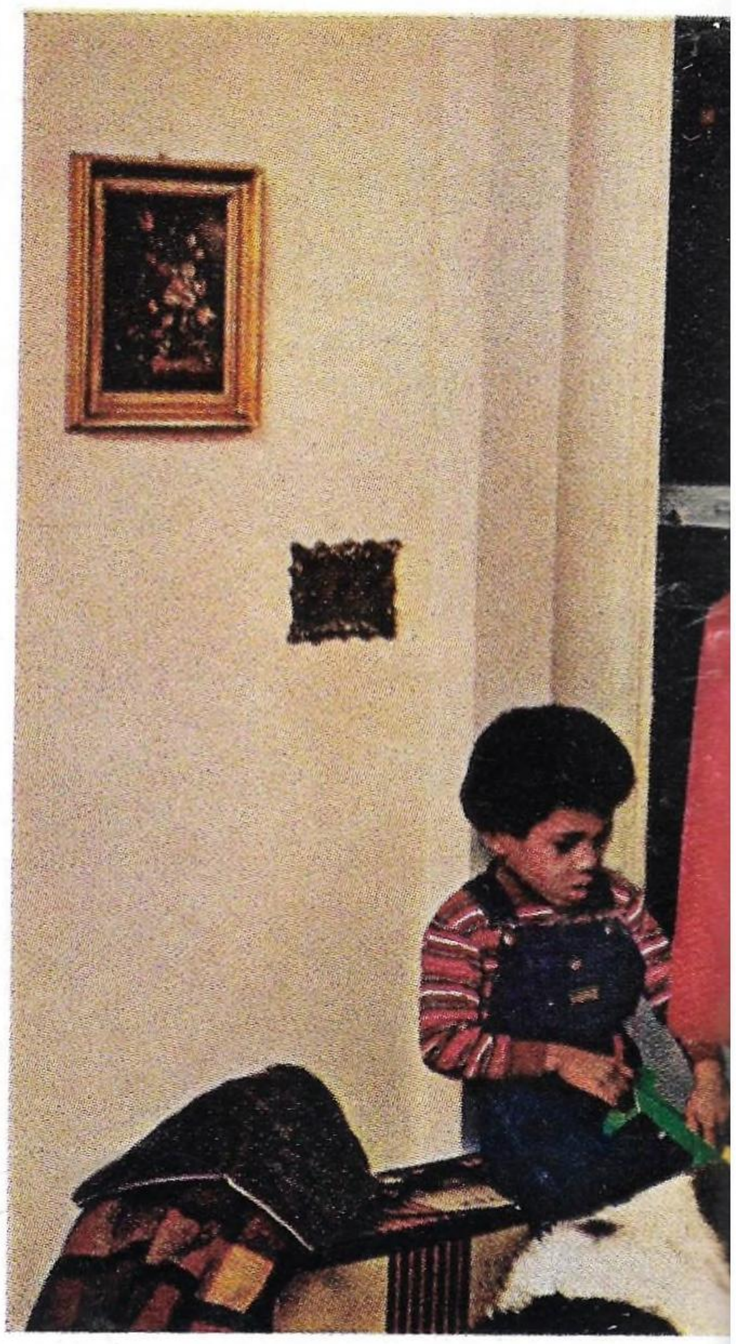
"About a year ago a group of scientists, in particular Drs. F. G. Banting and C. H. Best, working in the physiological laboratories of the University of Toronto, announced they had discovered a preparation that possessed the marvelous property of lowering the sugar content of the blood of dogs, when it was injected into them by means of a hypodermic syringe. This discovery was epoch-making in the history of medicine. The extract was made from the pancreas of animals, particularly the dog, the rabbit and the unborn calf. The process of making the extract has been applied on a commercial scale, and in this country there is at least one drug house that is ready to supply insulin in regular quantities. Insulin is not a permanent cure of diabetes; patients must keep on taking the drug constantly."

"The Bureau of Standards recently announced that the nearest approach to the absolute zero temperature that has yet been attained was recently achieved by Professor H. Kamerlingh Onnes of the University of Leyden. The record temperature of 272.18 below zero Centigrade, or, as the physicists express it, .82 degree absolute, was reached by the Dutch scientist in an unsuccessful attempt to solidify liquid helium. At that temperature the liquid helium showed absolutely no tendency to solidify. Every gas has been both liquefied and solidified except helium, which has never been reduced to the solid state."

SCIENTIFIC AMERICAN

OCTOBER, 1873: "The system of transporting oil by means of pipes laid over moderate distances has been in practice in the oil districts of Pennsylvania for several years. It remains yet to be determined whether the project can be carried out on a gigantic scale over more extended space. With the late discoveries in Butler County, Pa., the idea of transporting oil through iron pipes, from Titusville over the Alleghanies to Philadelphia on the sea board, a distance of 260 miles, is now exciting considerable attention. Mr. G. W. Platt, an engineer, gives detailed specifications for the construction of a huge conduit of this description. It is proposed to lay a cast-iron six-inch pipe, which at one locality of its route will be 3,000 feet above the sea level. Eight pumping stations will be established. Mr. Platt con-





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Glass. It's a natural.

cludes that 23,000 barrels can be delivered every 24 hours, at 10 cents per barrel."

"The discovery of a human skeleton in one of the grottoes of Menton, a village on the south coast of France near Nice, has produced no small excitement in the scientific world. It appears from the recent investigations of M. Rivière that, at the upper portions of the caverns examined, remains of instruments and tools were found belonging to the prehistoric epoch that immediately preceded, in the west of Europe, the appearance of metals. While the fauna discovered in connection with the human relics indicate a very ancient paleontological epoch, the bone and stone instruments seem to point to a more recent period. The multiplicity of bone tools, needles, chisels and a *baton* of command, together with a peculiar necklace that closely resembles one found on the fossil man of Cro-Magnon, lead to the conclusion that the series of objects belongs to an age posterior to that of the bear, namely to that of the reindeer. It is believed, however, that the original owner of the skeleton existed during the latter age, and was buried in a cave formerly inhabited by men of the preceding epoch."

"The good news comes to us from Dundee, Scotland, of the safe arrival there of all the remaining survivors of the Hall arctic expedition, consisting of Captain Sidney O. Buddington and 12 others. The incidents and results of this latest polar exploration can be briefly summed up as follows: On the 29th of June, 1871, the steamer *Polaris*, Captain Charles F. Hall, sailed from New York on a voyage of arctic exploration. In August, 1871, she reached latitude 82°16′, the highest point ever attained by any vessel. Soon after the ship went into winter quarters Captain Hall was taken ill, and he died on November 8, 1871. Captain Buddington became master. In August, 1872, finding further progress northward impossible, Captain Buddington determined to return home, and the ship started for the south. She was now caught in the ice, and Captain Buddington caused a portion of the provisions and a part of the ship's company to be landed on the ice. On the night of October 15, the *Polaris* broke away from her icy moorings, leaving the hapless party of 19 persons on the ice. On the 30th of April, 1873, after 6½ months of dreary drifting, they were rescued and were safely landed at St. John's, Newfoundland."

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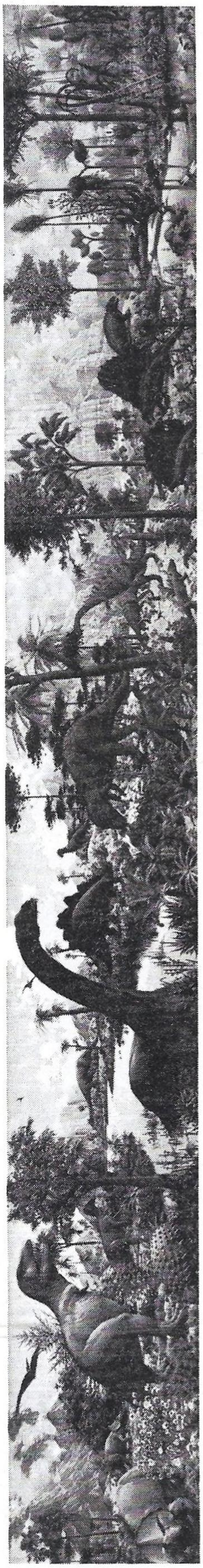

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THE AUTHORS

HENRY H. KOLM and RICHARD D. THORNTON ("Electromagnetic Flight") are respectively senior scientist at the Francis Bitter National Magnet Laboratory and professor of electrical engineering at the Massachusetts Institute of Technology. Kolm received his degrees from M.I.T. in physics: his bachelor's degree in 1950 and his Ph.D. in 1954. He is a founder of the National Magnet Laboratory and has a background in low-temperature and solid-state physics, cryogenic engineering, the generation of very intense magnetic fields (and their application to research and industry) and the development of superconducting-magnet systems. Thornton received his bachelor's degree in electrical engineering from Princeton University in 1951 and his Ph.D. in the same field from M.I.T. in 1957. Kolm and Thornton write that they have spent many hours cultivating their "feeling for vehicle dynamics," Kolm by flying and Thornton by sailing.

KEEN A. RAFFERTY, JR. ("Herpes Viruses and Cancer"), is professor of anatomy and head of the department of anatomy at the University of Illinois Medical Center in Chicago. Following his graduation from the University of New Mexico in 1950 he did graduate work in zoology, obtaining his Ph.D. from the University of Illinois in 1955. "My thesis topic," he writes, "involved the mechanism of formation of spontaneous tumors in frogs. In order to extend my experience to studies of tumors in mammals and birds I did three years of postdoctoral work at Yale University. From there I went to the Johns Hopkins University School of Medicine, where I taught anatomy for 12 years and did further research on tumors of frogs and mammals. Since I moved to Chicago in 1970 my interests have come to center almost entirely on human tumors."

MANFRED KORFMANN ("The Sling as a Weapon") is referent for prehistory and Near Eastern archaeology on the staff of the German Archaeological Institute in Istanbul. He received his Ph.D. in archaeology from the University of Frankfurt am Main in 1970. Before he began his university studies he spent a year in Jordan, teaching sports and German, and it was then that he became interested in Near Eastern studies. He notes that he has "some skill with both the sling and the bow."

D. E. KOSHLAND, JR. ("Protein Shape and Biological Control"), is professor of biochemistry and chairman of the department of biochemistry at the University of California at Berkeley. He received his bachelor's degree there in 1941 and his Ph.D. from the University of Chicago in 1949. He was associated with the Brookhaven National Laboratory and Rockefeller University until he returned to Berkeley in 1965. "As I grow older," he writes, "I note that my non-science diversions—reading, book-collecting, tennis and politics—consume a smaller fraction of my time. After shedding a few crocodile tears, however, I realize this is the result of my own selection. Thus at the moment the puzzles in neurobiology intrigue me more than novels or tennis (possibly because my tennis gets poorer). My wife is professor of immunology and bacteriology at the University of California; we are close enough in fields to enjoy discussing science but far enough apart so that we are not tempted to boss each other's research."

JAY M. PASACHOFF ("The Solar Corona") is director of the Hopkins Observatory at Williams College and assistant professor of astronomy there. He was graduated from Harvard College in 1963, receiving his master's and doctor's degrees at Harvard also. He spent two years at the Hale Observatories and the California Institute of Technology before going to Williams last year. Pasachoff is interested in photography and also reports that he has found his return to New England good for his squash game. He is given to composing light verse, some in the form known as the double dactyl, which has achieved a certain notoriety. He gives the following example, titled "A Biographical Addendum":

Higgledy-piggledy,
Jay Myron Pasachoff,
Williams astronomer,
Dabbles in rhyme.

Solar eclipses and
Radiotelescopes
Keep him contented
The rest of the time.

OLLE BJÖRKMAN and JOSEPH BERRY ("High-Efficiency Photosynthesis") are with the department of plant biology of the Carnegie Institution of Washington in Stanford, Calif. Björk-

man, who was born in Sweden, obtained his Ph.D. (in genetics) from the University of Uppsala in 1960, having previously studied at the University of Stockholm. In addition to his work at the Carnegie Institution, which he joined in 1964, he is associate professor of biology at Stanford University. He describes his nonprofessional interests as hiking, boating and fishing. Berry received his bachelor's degree (in chemistry) and his master's degree (in soil science) at the University of California at Davis in 1963 and 1966 respectively and his Ph.D. (in botany) at the University of British Columbia in 1970.

GERALD OSTER ("Auditory Beats in the Brain") is professor of biophysics and research professor of obstetrics and gynecology at the Mount Sinai School of Medicine of the City University of New York. Oster's Ph.D. is from Cornell University; he has served on the staff of the Rockefeller Institute for Medical Research and was professor of polymer chemistry at the Polytechnic Institute of Brooklyn (now of New York) before going to Mount Sinai. He writes that his current interest is "mainly in the area of population control" and involves "trying to find simple tests (chemical or psychophysical) whereby a woman can by herself anticipate when she will ovulate."

ALAN M. LITKE and RICHARD WILSON ("Electron-Positron Collisions") are respectively physicist at the Lawrence Berkeley Laboratory and professor of physics at Harvard University. Litke was graduated from Johns Hopkins University in 1964 and obtained his master's degree and his Ph.D. at Harvard, where he remained as a research fellow in physics until going to Berkeley in May of this year. He writes: "I have often combined my scientific activities with my other interests. In 1965 I hitchhiked from Amsterdam to Athens on my way to work at the Weizmann Institute of Science in Israel. In 1968 I traveled around the world via Siberia and the colliding-beam research facilities of the Academic City outside Novosibirsk. This trip included diving for shellfish with the Ama divers of Japan and snorkeling off the Hawaiian island of Maui. The possibility of combining science and art has intrigued me for some time. I have collaborated with artists on sculptures that display scientific phenomena in an artistic setting." Wilson, who was born in England, obtained his degrees at the University of Oxford. He has been at Harvard since 1955.

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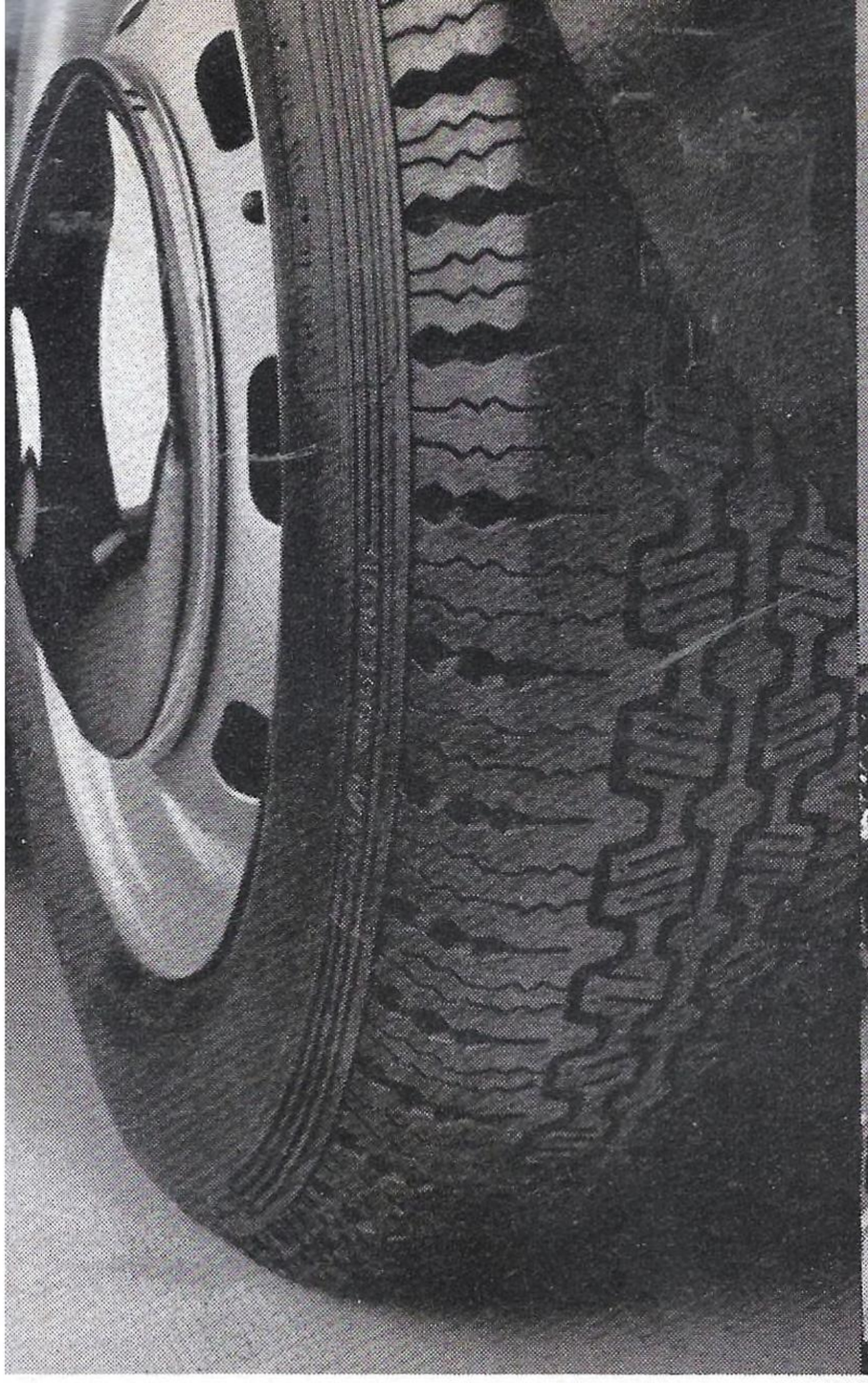

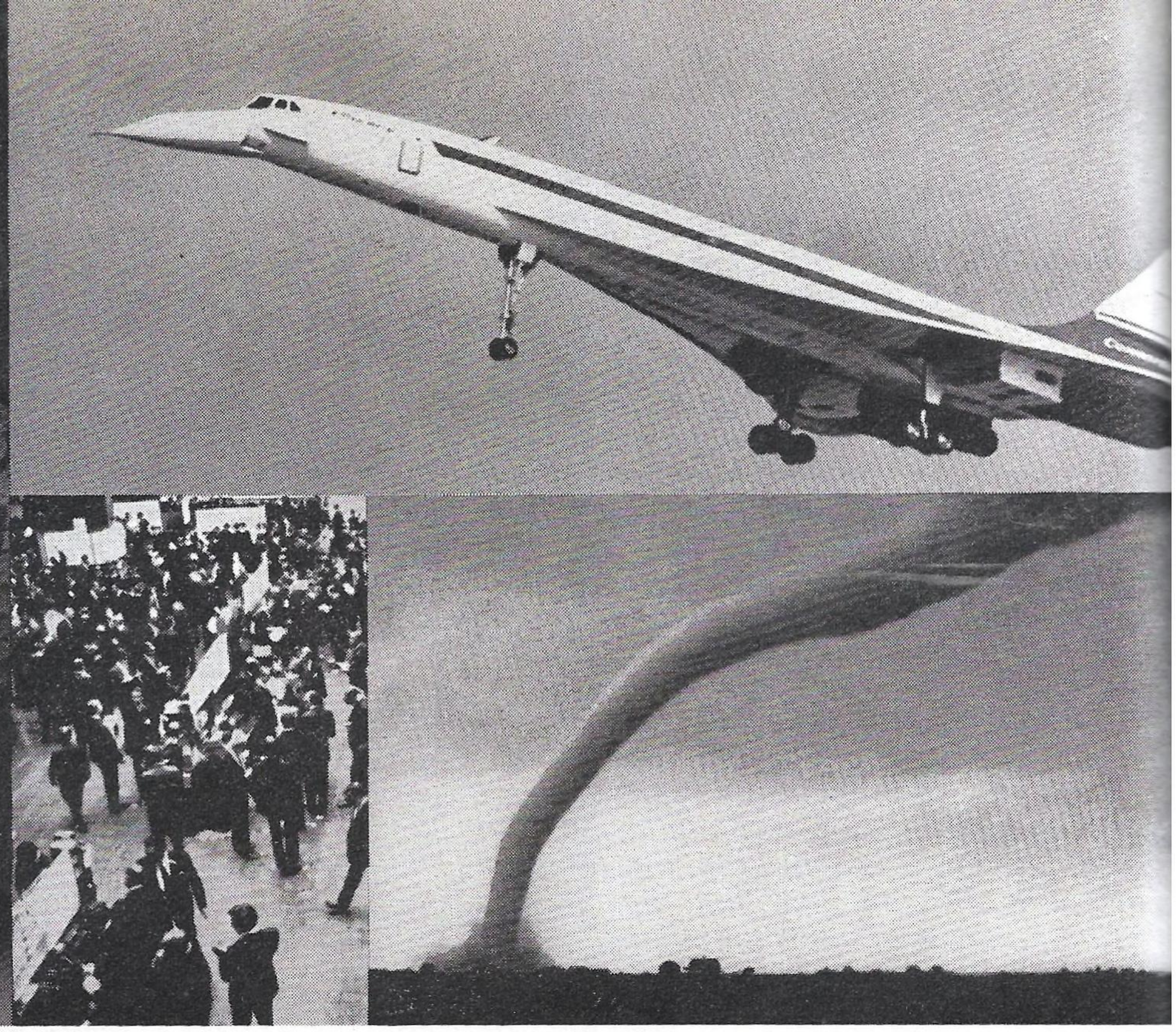

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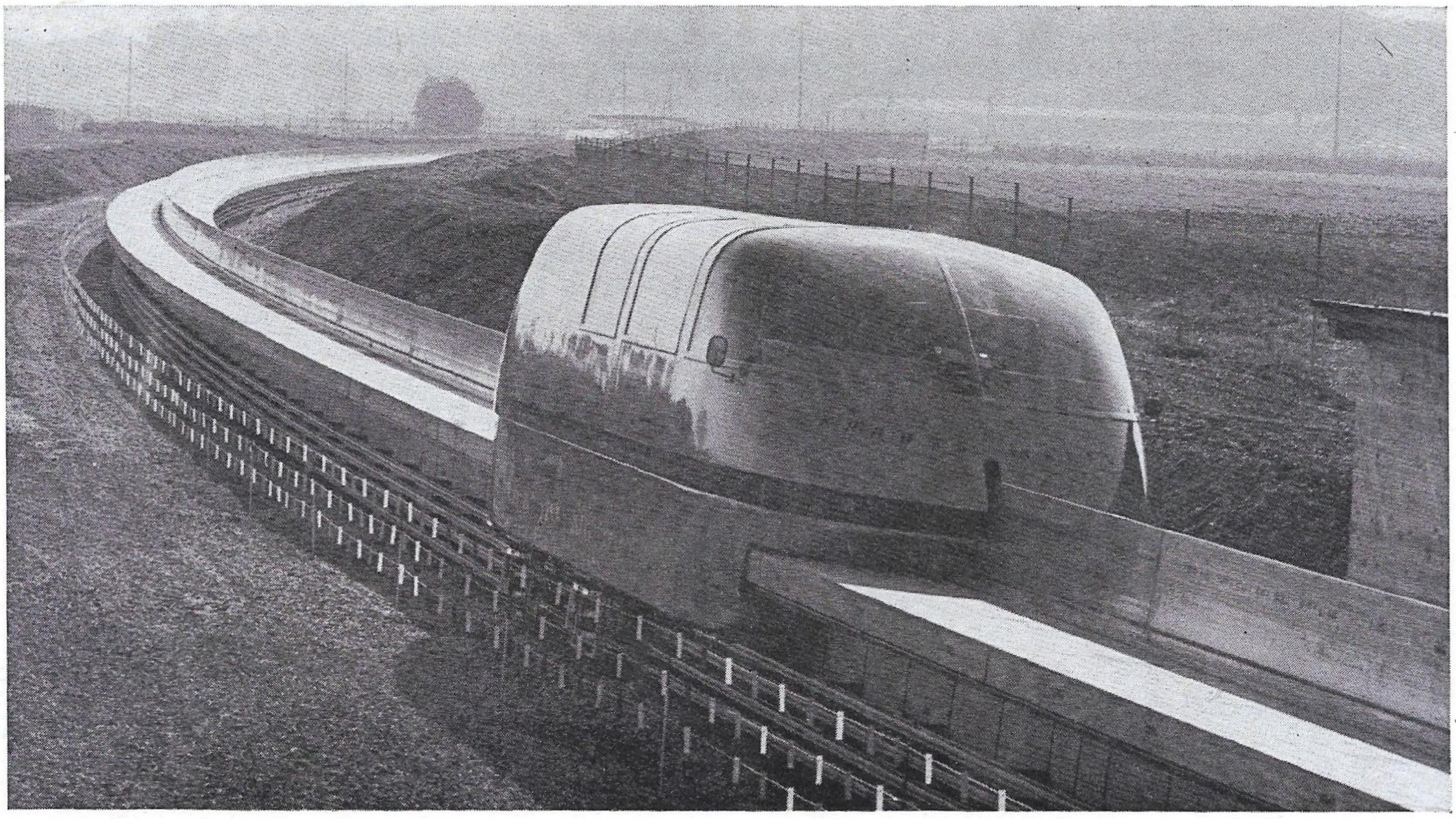
Established 1845 October 1973 Volume 229 Number 4

Electromagnetic Flight

The future of high-speed ground transportation may well lie not with wheeled trains but with vehicles that "fly" a foot or so above a guideway, lifted and propelled by electromagnetic forces

by Henry H. Kolm and Richard D. Thornton

Public transportation employing vehicles with wheels appears to be incapable of speeds much above those attained now by technologically advanced railroads. Since a number of valuable purposes would be served by ground transportation at higher speeds, various alternatives to the wheel are being investigated in Germany, Japan, the United Kingdom, Canada and the U.S. Among the alternatives are air-cushioned transport, attractive magnetic levitation and repulsive magnetic levitation. In these studies it is becoming increasingly clear that the future in high-speed ground transportation belongs to vehicles that "fly" about a foot above metal guideways, being supported, guided and propelled by electromagnetic forces. With the technology available today, such systems could operate in the range



ELECTROMAGNETIC VEHICLE developed by a German consortium is operated on a test track. The vehicle runs about one centimeter above the guideway, employing the form of magnetic levitation termed attractive levitation. It is propelled by a linear induction motor that straddles the vertical aluminum reaction rail. Car shown is a test vehicle carrying passengers and instruments.

of speed from 200 to 300 miles per hour, serving certain corridors (Boston-Washington, San Diego–Los Angeles–San Francisco, Houston-Dallas and others) where the density of traffic is already sufficient to bear the cost. Eventually, as the technology improves and demand increases, such systems could span continents, operating in partly evacuated tunnels and moving at speeds limited in theory only by the inevitable curvature of their path. Electromagnetic flight holds the promise of being a juncture in transportation history comparable to the advent of the wheel, the automobile and the airplane.

Like other transportation systems, electromagnetic flight must evolve considerably before reaching a commercial scale. The course of its evolution depends as much on the socioeconomic climate and on national commitments as it does on scientific and technological progress. Public understanding of the issues and problems involved is vital. We therefore undertake here to review both the historical and the technical aspects of the subject.

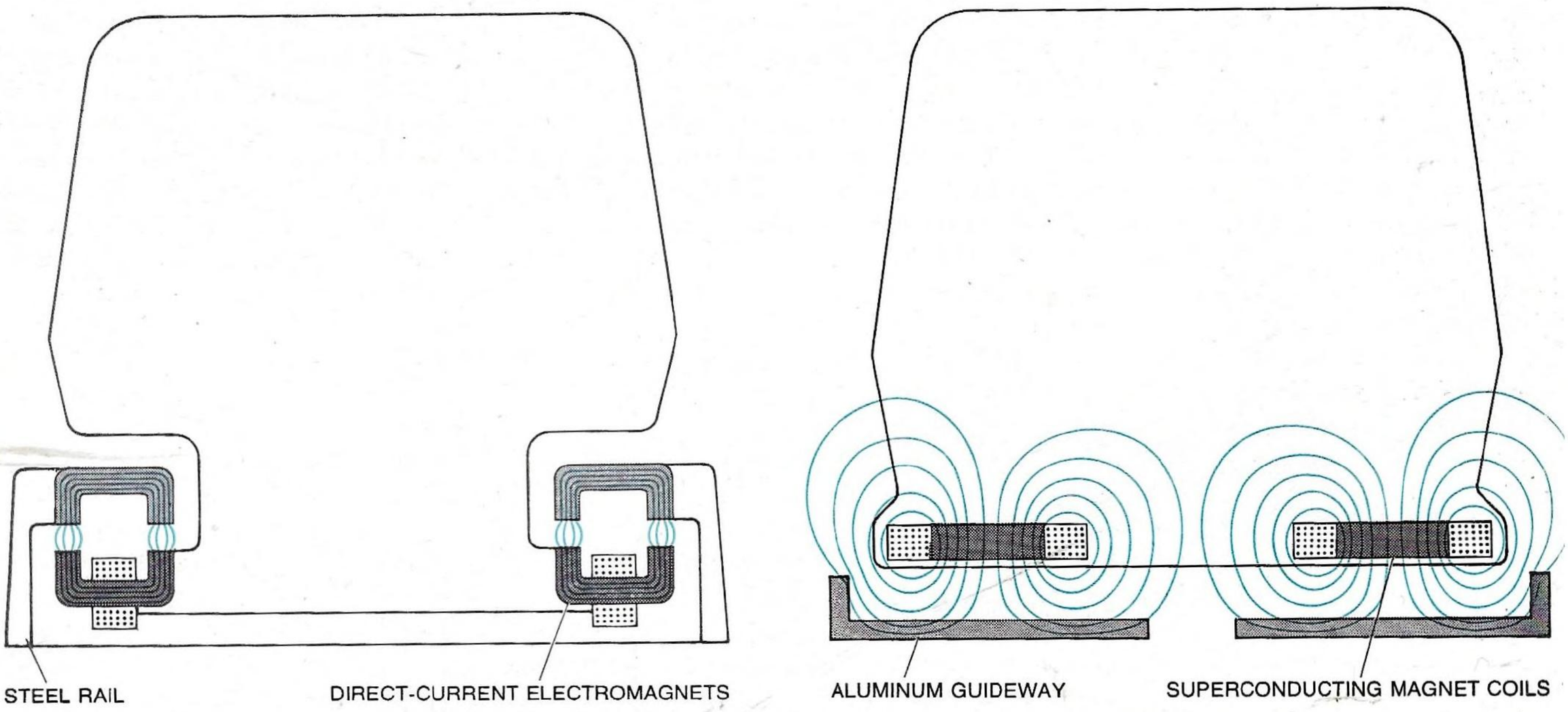
The first stage of the evolution began in the early 1960's with the realization by people concerned with ground transportation that fundamental innovations in technology were needed. Traffic on the highways and airways of several high-density corridors in the world was approaching saturation. The Japanese National Railways had just demonstrated the practical limits of conventional trains, finding that the traction and centrifugal strength of wheels and the frictional heating of pantograph current-collectors meant that such a train could not be operated regularly at a speed of more than about 200 miles per hour. In fact, the New Tokaida Line was unable to achieve day-to-day operation above 135 miles per hour, notwithstanding nightly realignment of the all-welded tracks and readjustment of the meticulously designed catenary cable. As a result of these findings many people started looking for alternatives to the wheel. From these efforts emerged what can be called the first generation of wheelless trains.

At the time the tracked air-cushion vehicle appeared to be the most logical alternative. Large untracked hovercraft had been built, and the technology of air cushions seemed to be well in hand. The British developed their Hovertrain, the French their Aerotrain and the U.S. Federal Railroad Administration its TACV. For various reasons, however, the development of air-cushion vehicles has not met with much success. The Hovertrain was officially terminated last February, construction of the Aerotrain has been postponed repeatedly and the TACV is now viewed primarily as a source of valuable information and by-products, notably the high-speed test facility built at Pueblo, Colo., as part of the program.

Magnetic levitation was also a well-known concept in 1965, the earliest proposal on record having been made in 1912 by the French engineer Émile Bachelet. Some of the early schemes were economically impractical, such as those that involved paving a guideway with permanent magnets to repel an oppositely magnetized vehicle. Others required supporting technology that existed but was unknown or at least untried in the context of railroad engineering.

Two entirely different approaches to magnetic levitation (which is often shortened to "maglev") are being pursued. One is attractive (or ferromagnetic) levitation, which involves vehicle-borne electromagnets that cling without contact to the underside of a suitably shaped steel rail or channel [*see illustration at left below*]. The system is inherently unstable because the attractive force increases as the magnet in the vehicle approaches the rail, requiring artificial stabilization by means of high-power, solid-state electronic feedback systems that regulate the current of the magnet so as to prevent contact.

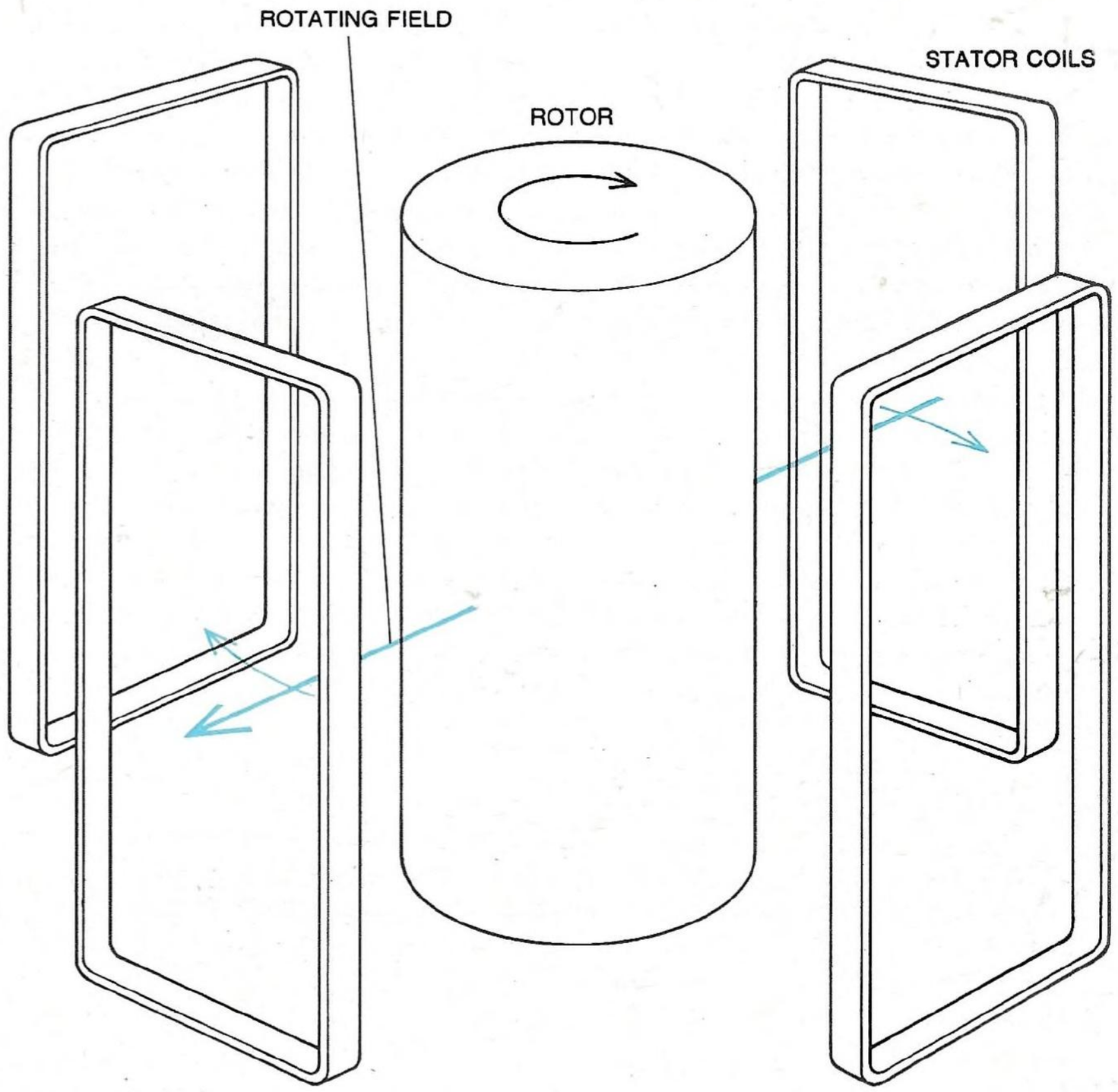
In such a system the amount of continuous power required to maintain lift remains quite reasonable (about two kilowatts per ton) up to clearance gaps of about two centimeters, although the peak power required to adjust the lift force increases rapidly as the amplitude and frequency of the required adjustments increase. A system employing attractive magnetic levitation therefore must have accurately aligned guide rails if high speeds are to be achieved. The exact trade-off between cost and speed



ATTRACTIVE AND REPULSIVE LEVITATION are portrayed. Attractive levitation (*left*) is based on electromagnets that cling without contact to the underside of a steel rail. Repulsive levitation (*right*) is based on the repulsive force experienced by a magnet moving above a conducting, nonmagnetic surface. With superconducting magnets, which carry large persistent currents if kept at a low temperature, repulsive levitation can lift a vehicle about a foot above the guideway. Magnetic fields are depicted in color.

is a controversial and largely undetermined issue. Although attractive magnetic levitation may not offer significantly higher speeds than wheeled systems, it does offer certain competitive advantages, including superior quality of ride, elimination of wear and greatly reduced noise.

The second approach to magnetic levitation is repulsive (or induced) levitation, which is based on the repulsion induced by a magnet traveling above a conducting surface. The scheme is appealing because it opens the way not only to wheelless trains but also to a fundamental departure from wheeled transportation. With repulsive levitation one can attain the mode of travel that has been called electromagnetic flight, employing vehicles called "magneplanes." Like aerodynamic flight, electromagnetic flight depends on a lift force derived from a vehicle's forward motion; the force is resilient enough to decouple the vehicle from variations in ground level, so that comfortable travel is possible without a secondary suspension system. Unlike the airplane, however, the magneplane can be flown in close proximity to a guideway because the lift force is strongest as the vehicle approaches the guideway. In this fashion the vehicle is compelled to follow the guideway.



GENERALIZED MOTOR for a vehicle in electromagnetic flight can be represented by a cylinder, which is the rotor, that is subjected to a rotating magnetic field perpendicular to its axis. The field is generated by a set of two or more coils, called the stator, that are supplied with two or more phases of alternating current. If the cylinder is a conductor, the motor is called an induction motor because it is driven by currents induced in the rotor. If the cylinder is itself a magnet, the motor is called a synchronous motor. Each of these types of motor can be "unwrapped" into a linear structure for electromagnetic flight.

Conventional electromagnets (and even permanent magnets) are capable of induced levitation at small clearances, but they are incapable of producing magnetic fields of the size and intensity required for flight. What has made electromagnetic flight possible is superconductivity, which is the virtual elimination of resistance in a conductor if it is sufficiently cooled. For the present purposes it will suffice to say that a 12-gauge copper wire, limited in normal use to a capacity of 20 amperes, will carry 10,000 amperes if it is made of currently available superconducting materials and kept near the temperature of liquid helium (4.2 degrees Kelvin, or 4.2 degrees Celsius above absolute zero). Such a temperature can be maintained by means of a refrigerator employing a closed cycle of helium as a kitchen refrigerator employs a Freon cycle.

The phenomenon of electromagnetic flight can be demonstrated by simple experiments. If one replaces the blade of a circular saw or the abrasive wheel of a bench grinder or a disk sander with an aluminum disk several millimeters thick, the spinning disk will be found to repel a suitable magnet held near its periphery. Electromagnetic flight can also be simulated without motion. Ordinary 60-hertz alternating current supplied to a wreath-shaped coil of copper wire will levitate the coil above an aluminum plate that is half an inch or more thick, although heating of the suspended coil will limit the duration of the flight.

The effect is best understood in terms of loops. Assume that a loop carrying an electric current is made to move past a somewhat larger conducting loop that is short-circuited [*see upper illustration on next page*]. As the magnetic flux from the traveling loop begins to link the stationary loop, it induces an electromotive force, resulting in an induced current that circulates in the stationary loop and tends to oppose the change in magnetic flux through that loop. The induced voltage is proportional to the rate at which the magnetic flux through the loop is changing, and the current is determined by the inductance and resistance of the loop.

When the traveling loop is directly above the stationary loop, the flux linkage is no longer changing, the induced electromotive force falls to zero and the induced current begins to decay owing to resistive loss in the stationary loop. As the traveling loop moves beyond the stationary loop, the flux linkage begins to decrease and thus induces a voltage pulse that is equal but opposite to the one induced during the approach. This pulse therefore suffices not only to cancel the induced current but also to induce a slight opposing current that is equal to the amount by which the originally induced current has decayed. This residual current persists for a fraction of a second after the vehicle passes and is called the eddy-current wake.

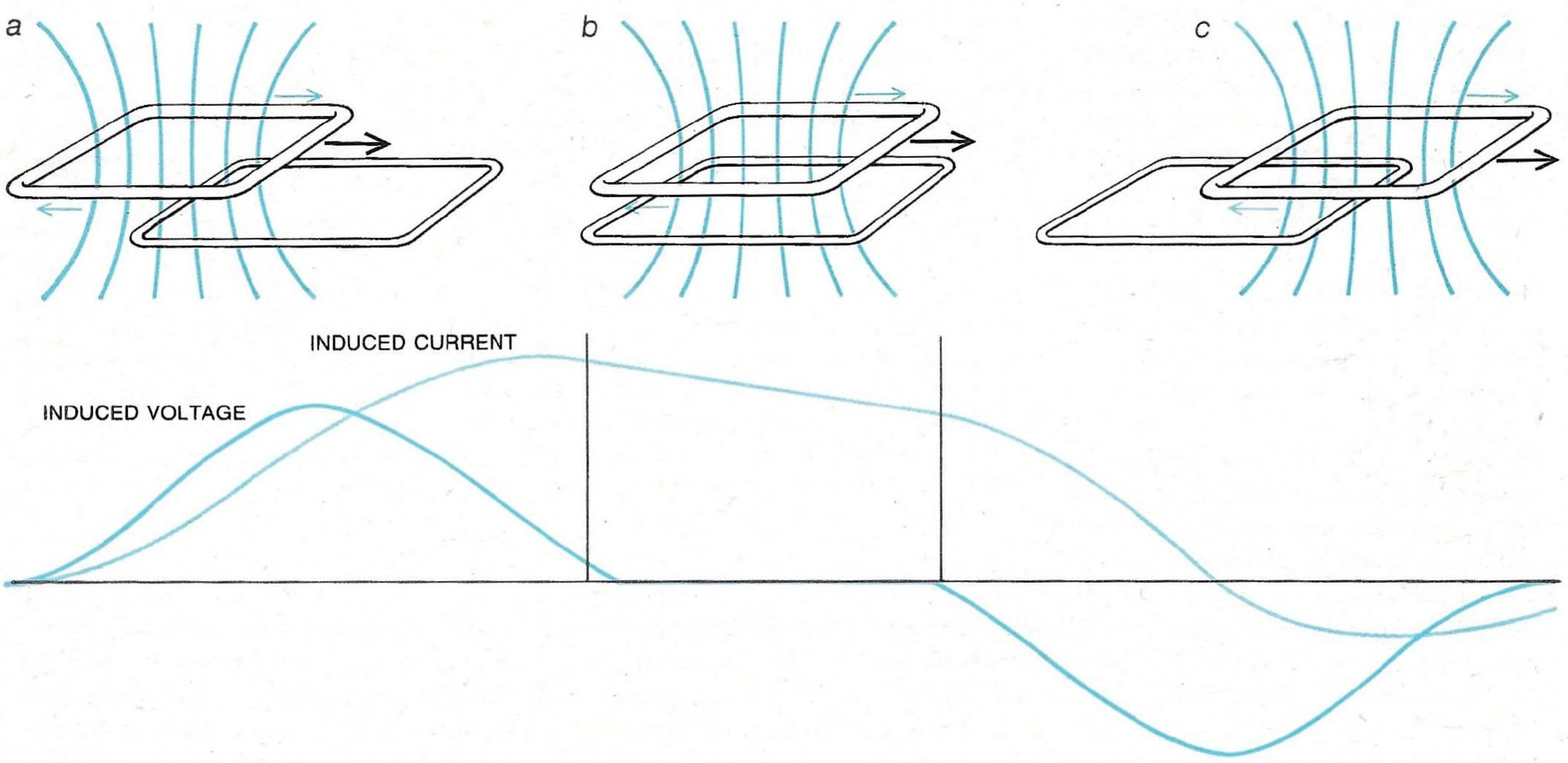
Both lift and drag are generated by the interaction of the two loops. Lift results from the fact that the induced current in the stationary loop flows in a direction opposite to the current in the approaching loop and therefore repels it. This repulsion alone would not produce drag, any more than drag is produced when a wheel is lifted by a cobblestone: all the energy lost in the approach is regained in the departure. Unfortunately, however, the electromagnetic cobblestone is not lossless. The cur-

rent in the stationary loop decays as the traveling loop passes, and therefore not all the approach energy is regained in the departure. The energy lost is just equal to the resistive dissipation in the stationary loop.

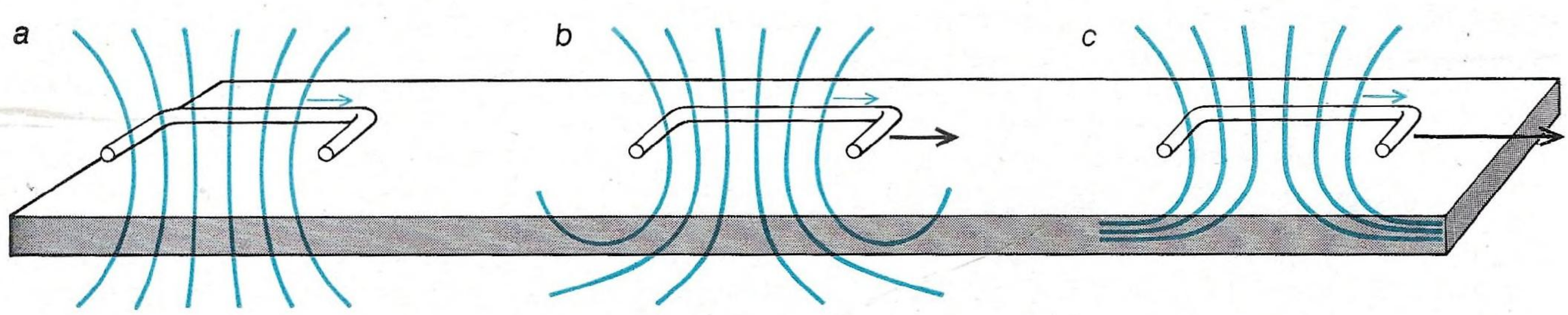
All the early investigators thought in terms of a guideway composed of discrete loops or coils, and there may in fact be certain advantages in such an arrangement. The guideway loops can be replaced, however, by a continuous conducting sheet without any fundamental change in the interaction. The conducting sheet (which we assume to be nonmagnetic) has no effect on the magnetic field of the current-carrying coil as long as the coil is stationary [*see lower illustration below*]. As the loop begins to move, currents are induced in the sheet; they oppose the local change in magnetic flux just as in the case of the discrete loop, except that these currents are distributed in the form of eddies and are called eddy currents. Their overall effect is to generate a magnetic field that opposes the field of the moving loop and keeps it from penetrating through the conducting sheet.

If the coil is moving rather slowly, some of the magnetic field still penetrates through the conducting sheet because the eddy currents have not become strong enough to keep it out entirely. As the traveling loop moves faster, however, it eventually reaches a speed at which none of the magnetic flux is allowed to penetrate. The sheet has become a magnetic shield. The moving loop now "sees" an image current of opposite direction, just as an electric charge facing a conducting sheet "sees" an image of opposite polarity. The image loop follows the real loop and repels it as if it were an equal distance behind the conducting sheet. The repulsive force becomes large as the moving loop approaches its image. This is the circumstance that makes electromagnetic flight susceptible to guidance.

With these principles in mind, one can understand the main characteristics of electromagnetic flight. If a current-carrying coil accelerates at a constant height above a conducting guideway, it experiences a lift force that is at



REPULSIVE LEVITATION is depicted schematically. As a current-carrying loop aboard the vehicle approaches a passive guideway loop (*a*), the increasing magnetic-flux linkage induces an electromotive force that drives a current around the guideway loop. The current tends to oppose the increasing flux linkage and thus repels the vehicle loop. When the vehicle loop is directly above the guideway loop (*b*), the magnetic flux is no longer increasing. The induced force falls to zero and the induced current begins to decay owing to resistance in the guideway loop. As the vehicle departs (*c*), the decreasing flux linkage induces an opposite electromotive force, which cancels the remaining current and induces a slight opposite and attractive current equal to the decay. Drag is caused by the decay and is therefore less the faster the vehicle travels. Decrease of drag with increasing velocity is rare in transportation.

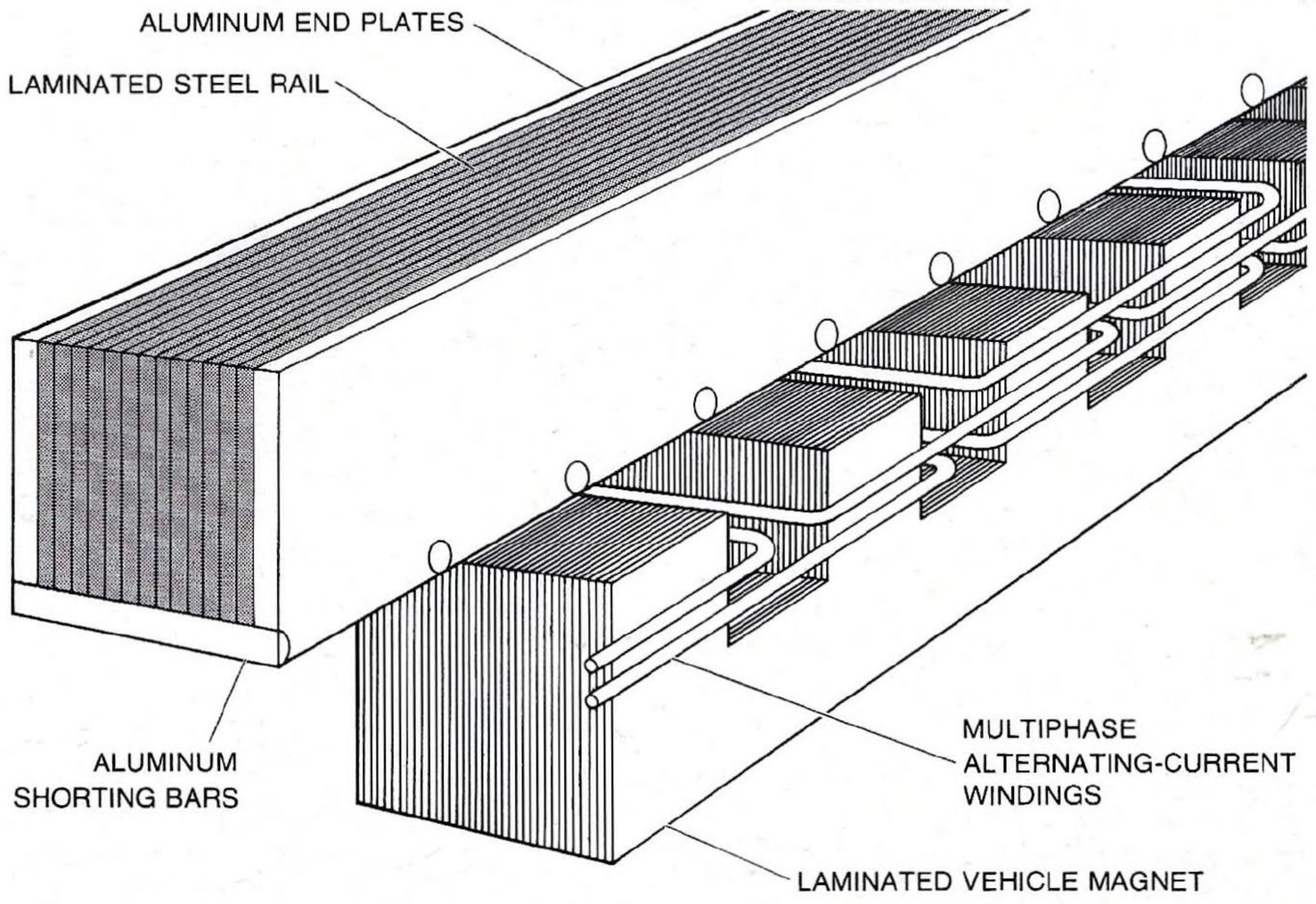


CONTINUOUS GUIDEWAY can also be employed in repulsive levitation. When the vehicle is stationary (*a*), the magnetic flux of the current-carrying vehicle loop is unaffected by the conducting, nonmagnetic guideway sheet. As the loop begins to move (*b*), eddy currents are induced in the sheet. They expel some of the magnetic flux and thus repel the moving loop. If the loop moves rapidly, most of the magnetic flux is expelled from the sheet, and the vehicle rides on a cushion of magnetic flux generated by an imaginary "image loop" of oppositely directed eddy currents that follows the real loop. The force increases sharply as the loop aboard the vehicle approaches the guideway sheet. It is this phenomenon that makes a vehicle in electromagnetic flight responsive to guidance.

first proportional to the square of velocity but eventually reaches a limiting value. The drag force is at first proportional to velocity but then passes through a peak value and decreases as the inverse of velocity. At high speeds the drag decreases more slowly because of the "skin effect," meaning that the induced eddy currents are prevented from penetrating into the metal and flow only in a thin layer called the "skin depth," so that the guideway appears to have higher resistivity. The fact that electromagnetic drag, unlike aerodynamic drag, decreases with increasing speed is a rather remarkable characteristic of electromagnetic flight.

For a practical guideway, takeoff becomes possible at 20 miles per hour, and the limit of lift is essentially reached at about 60 miles per hour. The lift is proportional to the product of the components of the magnetic field that are perpendicular to and parallel to the surface of the guideway, and the drag is proportional to the square of the component of the field that is perpendicular to the surface of the guideway. The lift-to-drag ratio is therefore proportional to the ratio of parallel components to perpendicular components of the magnetic field—a relation that gives some insight into the way the configuration of the magnets on a vehicle can be optimized.

If the magnetic field at the surface of a continuous-sheet guideway is 20 kilogauss (about the field strength at the pole face of a good magnet), the lift force is 60 pounds per square inch (about the pressure in a bus tire). This relation suggests that a bus could be levitated by magnet pads no larger than its footprint area—a circumstance that inspired the wheelless-train approach of the early investigators. Superconductivity was seen at first as simply a means for making such wheelless trains economically feasible. Its revolutionary possibilities went unrecognized for a surprisingly long time.



ATTRACTIVE-LEVITATION SCHEME developed by Rohr Industries, Inc., produces both levitation and propulsion. System employs multiphase alternating-current excitation and a laminated steel rail with aluminum shorting bars. Propulsion is by linear induction motor.

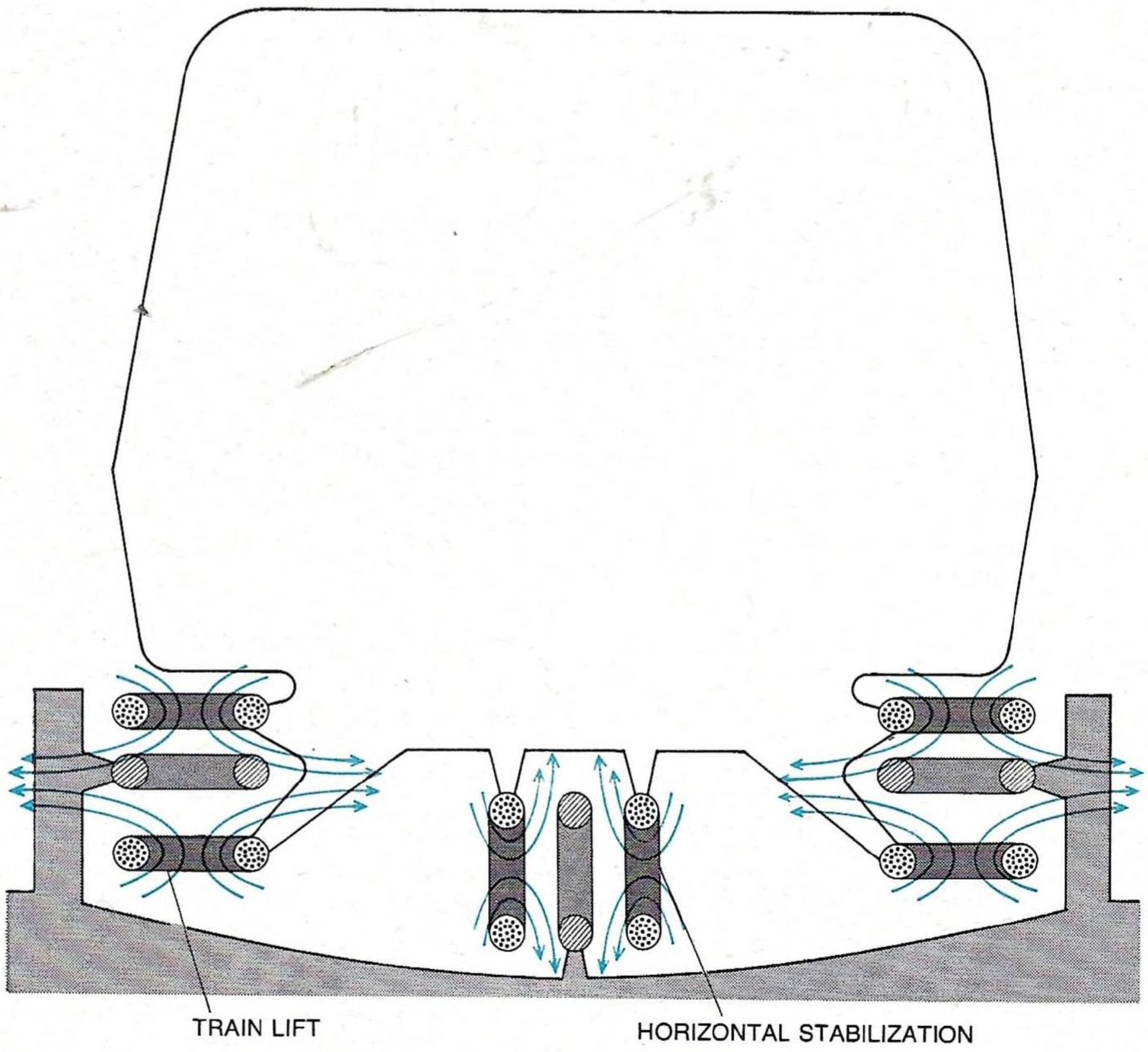
The evolution of electromagnetic flight is inextricably linked to the problem of propulsion. Two types of "linear motor" are being studied for this application. One is called the linear induction motor, the other the linear synchronous motor.

Many rotary electric motors can be represented by a cylinder subjected to a rotating magnetic field perpendicular to its axis [*see illustration on page 19*]. The rotating field is generated by a set of two or more coils supplied with two or more phases of alternating current; they are called the stator coils. If the cylinder is a conductor, such as an aluminum tube, the motor is called an induction motor because it is driven by eddy currents induced in the rotor by the rotating field of the stator. If the cylinder is itself a magnet (either a permanent magnet, an electromagnet or even a ferromagnetic structure), the motor is called a synchronous motor. An induction motor will supply torque even if its rotor is not in synchronism with the rotating field of the stator, although good efficiency is achieved only near synchronism. A synchronous motor, on the other hand, will supply no torque whatever once its rotor is pulled out of synchronism with the stator field. For this reason induction motors are used to start large synchronous motors and for applications involving loads and speeds that vary.

Both types of motor can be "unwrapped" into linear structures. The induction motor appeared to be the more obvious candidate for linearization because of its tolerance for variations of speed and because one of its two members can be simply a continuous strip of conducting material. Linear induction motors have received serious attention for many years, quite independently of magnetic levitation. Among other things, they serve to transport liquid metal and metal objects in conveyor lines consisting of a fixed array of magnets, representing linear stators, energized by alternating current. In transportation they were viewed as the only alternative to jet propulsion for tracked air-cushion vehicles; even earlier they were seen as a means of propelling wheeled vehicles above the speed at which wheel traction fails.

Propulsion by linear induction motors involves three serious problems. First, it requires that several megawatts of power be picked up from a live rail—a very costly operation that has yet to be solved for vehicles moving at high speeds. The alternative of generating power on board the vehicle is ecologically unacceptable, since it implies a 20,000-horsepower installation equivalent to a jet engine as a source of air and noise pollution, and the alternative of a fixed stator winding along the track is economically unthinkable. Second, to be reasonably efficient a linear induction motor must operate near synchronous speed, a performance that can be achieved only by carrying heavy frequency-conversion equipment on the vehicle in addition to the massive stator magnets. Third, the linear induction motor requires a clearance gap of about three-quarters of an inch between the stator and the reaction rail, which might be compatible with air-cushion transport or attractive levitation but would defeat the advantage of the much larger clearance made possible by repulsive levitation.

The linear synchronous motor was at first ignored because of its intolerance to variations of speed and its need for an expensive structure (either stator or rotor) along the entire track. The advent of superconductivity has changed the situation completely, so that the linear synchronous motor now appears to be the key to propulsion at high



NULL-FLUX SYSTEM was proposed by James Powell and Robert Danby of the Brookhaven National Laboratory. Two opposing coils on the vehicle carry a persistent superconducting current and straddle a single track loop. The system can also work with a single vehicle coil flanked by two track loops connected in opposition. This was the first scheme for repulsive levitation of high-speed transportation vehicles by superconducting magnets.

speeds. The superconducting levitation magnets provide magnetic fields that are not only very intense but also of large volume and can be efficiently coupled to fixed stator windings in the guideway, even at clearance gaps of about a foot. The increase in rotor current made possible by superconductivity opens the way to a reduction of the stator current and so to much simpler stator structures than were considered previously. As for the problem of synchronization, we have demonstrated at the Francis Bitter National Magnet Laboratory at the Massachusetts Institute of Technology that it can be solved easily by transmitting position information from the vehicle to wayside power-control units, which is much simpler than transmitting power from wayside units to a moving vehicle.

The development of magnetic-levitation systems has progressed quite far in Germany and Japan. In Germany two industrial teams (Krauss-Maffei and Messerschmitt-Bölkow-Blohm) have independently developed ferromagnetically levitated vehicles propelled by linear induction motors. By 1971 each consortium had completed a test track and an instrumented, passenger-carrying test vehicle. Both systems operate at a clearance of about one centimeter, with levitation magnets riding below an overhanging steel rail. A separate linear induction motor straddles a vertical aluminum reaction rail. Although the alignment requirements make for expensive construction, both systems represent serious competition for wheeled trains.

A third German consortium (Siemens, AEG-Telefunken and Brown, Boveri & Cie.) is pursuing a longer-range project involving repulsive superconducting levitation. The team has almost completed a circular test track 280 meters in diameter and is planning a 20-kilometer straight test section. All the German projects have had assistance from government ministries.

In Japan the Japanese National Railways (in collaboration with all the major electrical industries) decided after exhaustive study to adopt repulsive superconducting levitation with a small gap and with propulsion by linear induction motors. The plan was later modified by increasing the clearance gap to several inches and adopting linear-synchronous-motor propulsion. According to the schedule, a half-scale test vehicle will operate on a seven-kilometer test track by next year.

To complete our account of the first era of magnetic levitation we should mention a ferromagnetic attractive system being developed privately by Rohr Industries, Inc., of California. It differs radically from the two German systems in that the lift-magnet structure works on alternating current and is employed not only to lift but also to produce linear-induction-motor propulsion. The system has been demonstrated successfully at moderate speeds and may eventually provide the winning technology for a narrow-gap system.

The first proposal for the repulsive levitation of vehicles by superconducting magnets was published in 1966 by James Powell and Robert Danby of the Brookhaven National Laboratory. As physicists they were concerned with the design of magnets for confining, focusing and bending beams of high-energy charged particles. Although superconducting magnets were then being used by physicists, the broader scientific community had neither an interest in nor the money for applications of superconductors to transportation, and the transportation community viewed the proposal with more amusement than interest. Powell and Danby developed the concept in their spare time, with support (as they put it) from their wives.

Their first scheme involved a superconducting guideway, but they later refined what has come to be known as the "null flux" scheme, which is the basis of the system being implemented at full scale in Germany. Powell and Danby found that a significant reduction in drag can be achieved by arranging the guideway loops so as to achieve an extremely high field gradient, that is, a field intensity that changes drastically with changes in position. The feat is accomplished by having two opposing guideway loops flanking a single coil on the vehicle or, conversely, two opposing vehicle coils flanking a single guideway loop [*see illustration on this page*]. A null-flux suspension therefore provides not only a high lift-to-drag ratio but also strong restoring forces, or great stiffness. Unfortunately the system is so stiff that alignment of the guideway again becomes critical and a secondary suspension is essential. The secondary suspension creates added weight, aerodynamic drag and loss of power, which cancels much of the advantage in efficiency.

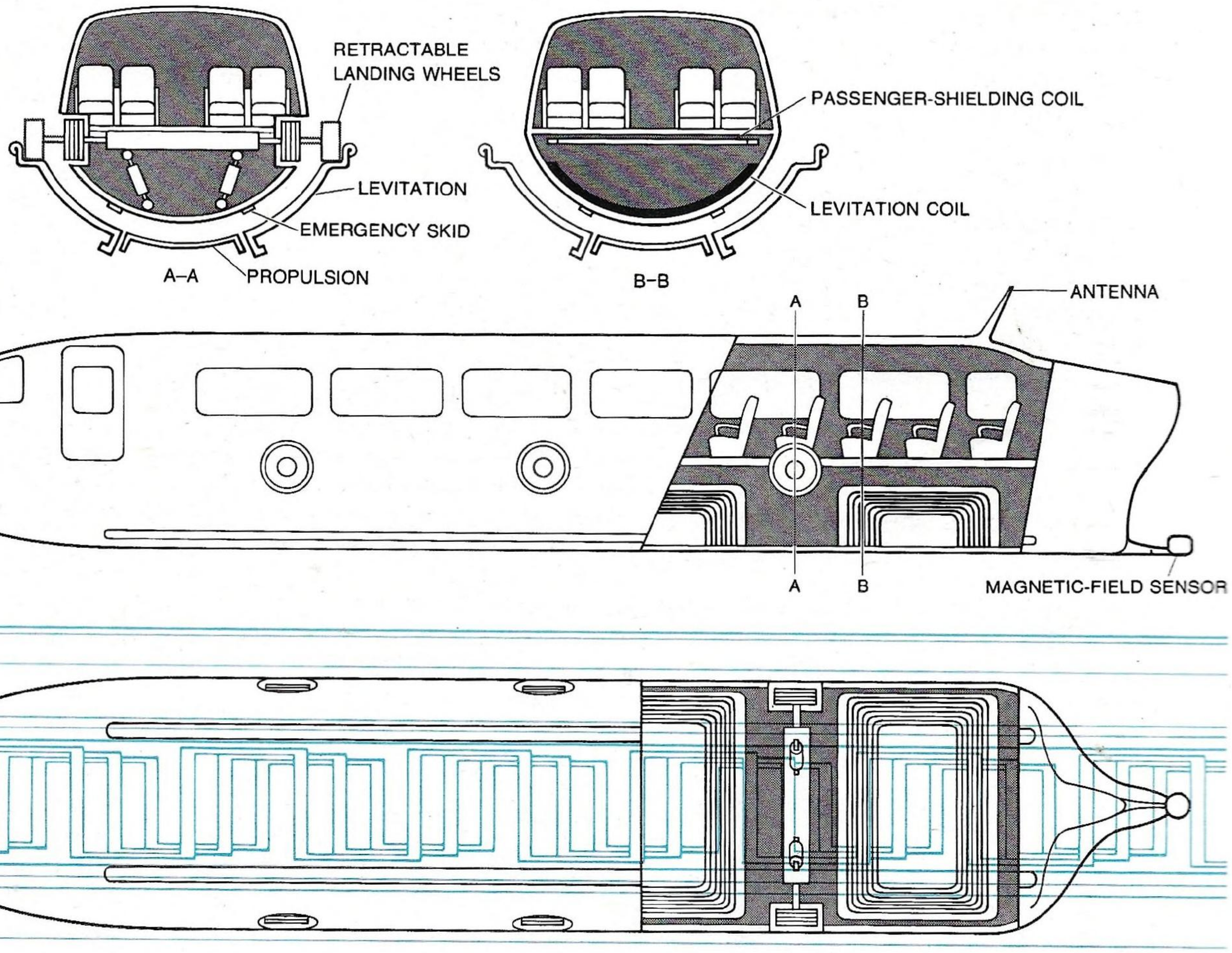
By 1969 several theoretical studies of inductive levitation had been published. Two of them are particularly noteworthy in the context of this article. C. A. Guderjahn, S. L. Wipf and several co-work-

ers, then at the Sandia Corporation, designed a guidance system for high-speed rocket sleds carried by two superconducting coils confined in *C*-shaped metal channels. This was the first proposal for a continuous-sheet guideway. The system provides very stiff suspension and high drag, owing to the fact that the magnetic field is predominantly perpendicular to the guideway sheets. Guderjahn and Wipf improved the lift-to-drag ratio, however, by adding a layer of steel to the upper leg of the channel so as to derive part of the lift by ferromagnetic attraction. A hybrid scheme of this kind has been adopted in the most recent variation developed by Powell and Danby and in one of the German projects. The second study was a detailed analysis of electromagnetic levitation and propulsion by Michael Tinkham of Harvard University and Paul L. Richards of the University of California at Berkeley.

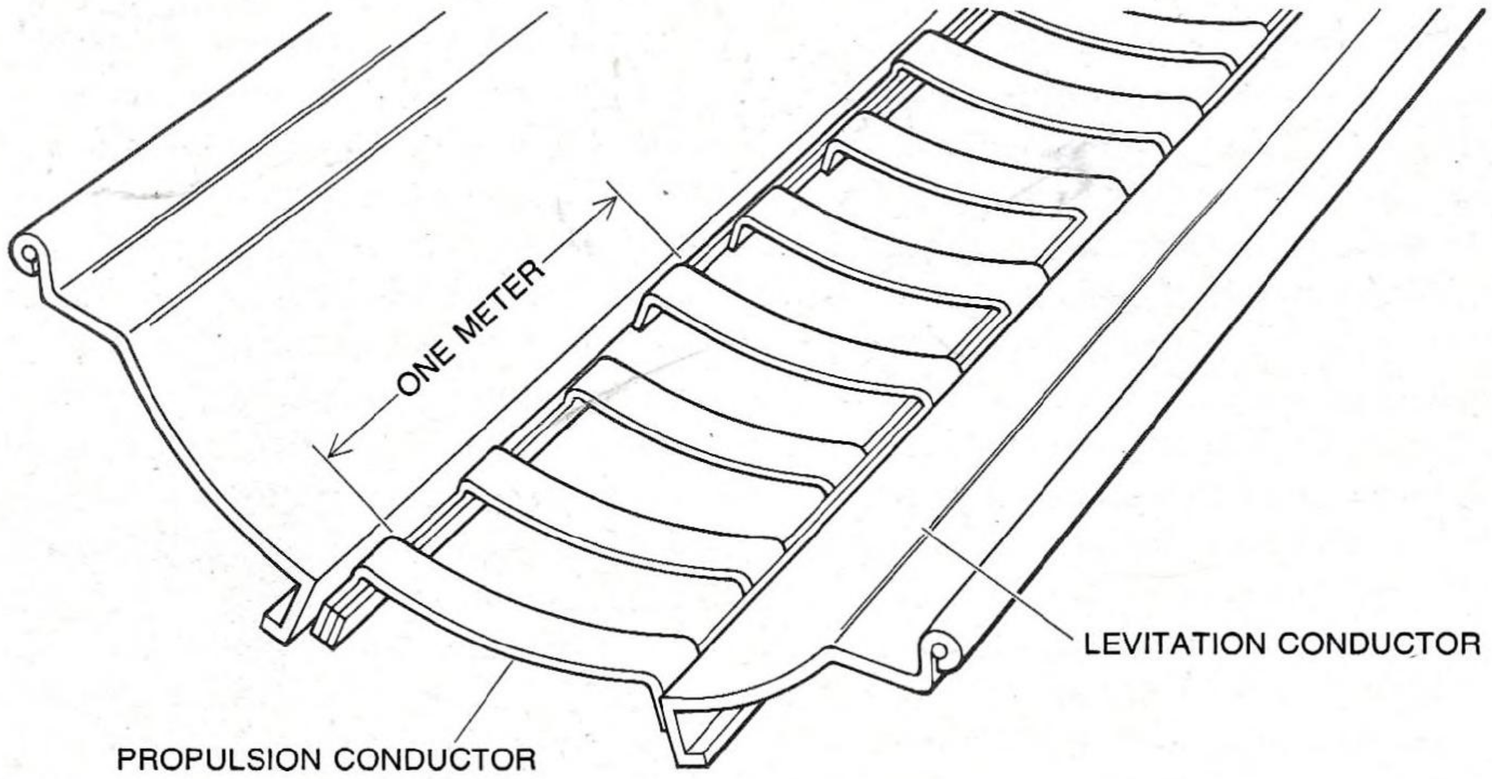
It was in 1969 that we initiated our work at M.I.T. on the magneplane system. We recognized that superconducting magnets offer the possibility of guided flight by lightweight vehicles, supported at an elevation of approximately one foot by resilient forces distributed evenly over a substantial area of the vehicle. This arrangement eliminates the most glaring absurdity of rail systems, in which massive girders in the vehicle concentrate the load onto two axle pads so that it can be carried at enormous pressure by two rails, whose concentrated load then has to be distributed over the ground by ties and ballast.

The magneplane is supported by saddle-shaped superconducting coils distributed essentially over its entire underside. It flies one foot above a semicircular aluminum trough, which allows the vehicle to assume a coordinated bank angle on curves in the manner of an airplane or a bicycle. (Self-banking is essential because even at a 45-degree bank, the steepest performed by an airplane, the tightest radius that can be negotiated at 300 miles per hour is one mile. If the bank angle were fixed by the guideway, even slight variations in speed would lead to unacceptable side forces on the passengers.) The weight of the vehicle is distributed over the guideway at about two pounds per square inch. The alignment tolerance is such that the guideway does not require a massive support bed and can be carried by light and flexible elevated structures resembling more the fuselage of an aircraft than a railroad bridge.

We also recognized that the propulsion system most compatible with electromagnetic flight is the linear synchronous motor, with stator coils along the guideway rather than aboard the vehicle. Other systems had eliminated active guideways categorically for economic reasons. In our system it turned out that the large, superconducting dipole magnets aboard the vehicle make it possible to have guideway coils that are considerably simpler than had been anticipated. The propulsion system consists of meandering conductors rather than coils, and



"MAGNEPLANE" VEHICLE developed by the authors at the Francis Bitter National Magnet Laboratory at the Massachusetts Institute of Technology is portrayed in cross sections (*top*), a side view (*middle*) and a bottom view, which also shows the guideway. The areas of the cross sections are shown by the lines *A—A* and *B—B*. The vehicle is designed to travel at speeds of from 200 to 300 miles per hour with levitation about a foot above the guideway by repulsive superconducting levitation and propulsion by a linear synchronous motor. At full scale the vehicle would be proportionately a considerable amount longer than the representation here.



MAGNEPLANE GUIDEWAY consists of meandering aluminum coils that serve as linear stators and are flanked by passive aluminum troughs that allow vehicle to roll into a coordinated bank angle in curves. Strong superconducting levitation coils on vehicle serve as rotor of a synchronous motor. Most of aluminum has both electrical and structural purposes.

we have managed to develop a guideway design in which most of the aluminum serves both structural and electrical purposes [*see illustration above*].

Detailed studies indicate that the cost of the guideway is comparable to that of any other projected high-speed system and that it is not in any way dominated by the fact that the propulsion system forms an integral part of the guideway structure. The linear synchronous motor thus offers a formidable combination of advantages: it eliminates the massive onboard equipment required for propulsion by the linear induction motor, along with the separate reaction rail, the narrow clearance gap and the need for a sliding power-pickup system. The reduced weight of the vehicle leads in turn to reduced costs for the guideway (a particularly significant factor in elevated construction) and reduced power requirements.

Synchronization of the linear synchronous motor is accomplished quite easily by transmitting position information from the vehicle to the wayside power-control units, which are positioned at intervals of about 10 miles. These units contain transformers and computers that actuate transformers and solid-state switches positioned at one-mile intervals along the guideway. The phase, frequency and amplitude of the multiphase propulsion current are automatically adjusted to maintain synchronous acceleration, deceleration and cruise. The system thus substitutes information transmission for power transmission.

Two additional advantages are inherent in the linear-synchronous-motor approach. First, positive control of each vehicle by wayside units connected to a central computer allows safe operation at the levels of traffic density and vehicle headway that are absolutely essential for the economic feasibility of any high-speed ground transportation system. Second, the system eliminates the shocks and lurches of wheeled systems and small-gap suspensions, thereby providing a comfortable ride that can be expected to make the system highly acceptable to passengers. The system does sustain slow oscillations (having a period of about one second) that are inherently underdamped and that cannot be damped completely by any known passive technique. We have found that the propulsion-control system provides a simple means for actively damping such oscillations. By adjusting the phase position of the propulsion on the basis of accelerometers carried on the vehicle, heave disturbances of considerable vertical force can be damped. Since the nonlinear repulsive force and the circular geometry couple heave with pitch, sway, roll and yaw, these other motions can also be reduced.

In sum, the magneplane can be likened to a magnetic surfboard riding the forward slope of a traveling magnetic wave whose speed of travel and height are constantly adjusted to keep the surfboard in smooth motion. The controlled "surf" also damps heave motions of the vehicle, thereby providing active control of the ride without the need for springs or shock absorbers, neither of which are very practical at high speeds.

The initial capacity of the guideway would be 6,000 passengers per hour in each direction. It could probably be doubled as the technology matures. The magneplane concept differs fundamentally from conventional railroad thinking: instead of providing 50 megawatts of wayside power capacity to propel a 1,000-passenger train every hour, it provides five megawatts of wayside power to propel a lightweight 100-passenger vehicle every minute. The achievement is made possible by off-line loading and automatic, positive control of all motions of the vehicle. Conventional railroads are basically linear; applied to the Northeast Corridor, for example, they can provide 10-stop trains at hourly or half-hourly intervals. Magneplanes, on the other hand, could serve dozens of stations connected by branch loops, with vehicles operating at one-minute intervals and none of them making more than one or two stops between Boston and Washington.

Initial development of the magneplane at our laboratory was supported by funds from the Sloan Foundation. The effort was later joined by the Avco Systems division of the Avco Corporation, the Raytheon Equipment Division and United Engineers and Constructors, Inc., with material support by the 3M Company and ALCOA. In this way a team of investigators with skills in numerous disciplines was brought to bear on the project. From M.I.T. the chief participants are Yukikazu Iwasa, Sanborn C. Brown, Joel H. Schultz and Robert C. Wallace. The results have had an influence on thinking about magnetic levitation and have also led to support by the new division for Research Applied to National Needs of the National Science Foundation. In addition to detailed studies of the need for a full-scale system, the work has progressed to the construction of a fully operational scale-model magneplane system that will soon be demonstrated publicly.

During this time the Federal Railroad Administration has been grappling with the problem of obtaining a factual base for a policy decision on the technology of high-speed ground transportation. Having committed some $30 million to the development of tracked air-cushion vehicles propelled by linear induction motors, the agency was reluctant to ask Congress to support a major program on magnetic levitation simply because Germany and Japan had done so. Between 1971 and early 1973 the agency provided money for analytical studies of magnetic levitation by the Ford Motor Company and the Stanford Research Institute; the studies confirmed the practical feasibility of both attractive and repulsive levitation and identified the essential requirements and problems in both areas.

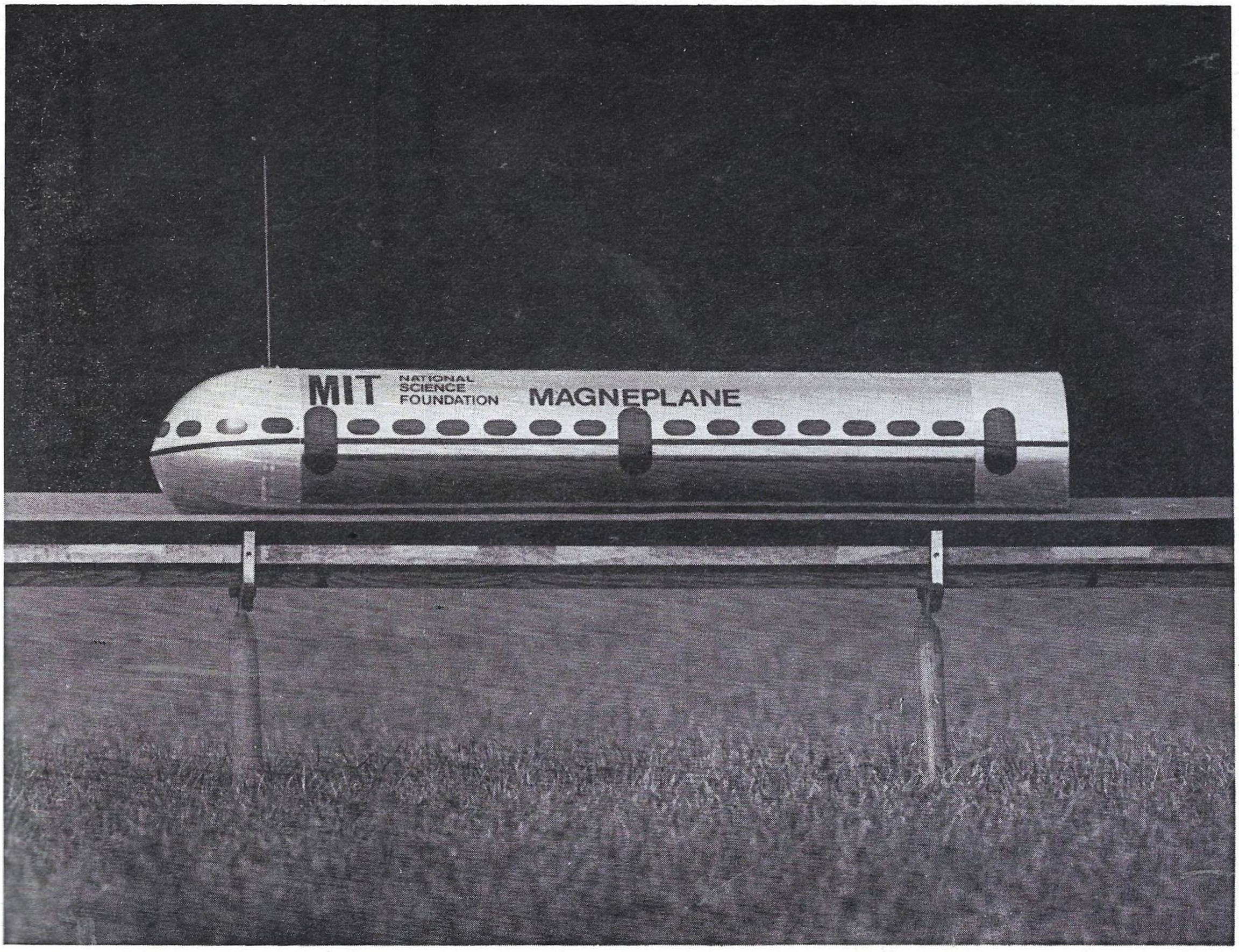
The Federal Railroad Administration

did not view these studies as conclusive, however, and is now embarking on full-scale rocket-sled tests at 300 miles per hour on specially built one-kilometer tracks. The objective is to be able to choose by 1975 between what the agency regards as two alternative developments, neither of which can be clearly defined as a necessity. Unfortunately the special equipment constructed in a four-month design period will bear little resemblance to the passenger-carrying system that might eventually evolve from either approach to magnetic levitation, nor will the rocket tests provide meaningful information on propulsion, economics, quality of ride or acceptance by passengers.

It is both amusing and sobering to reflect on an analogous situation some 50 years ago, when airships and airplanes were the competing technologies for high-speed transportation. Airships were engaged in a profitable transatlantic passenger service, whereas airplanes had failed to show commercial potential, even after two decades of development. It is fortunate that the course of aviation was not determined by an irrevocable Government decision, no matter how wise it may have seemed at the time. It was determined in bicycle factories and barns by a handful of entrepreneurs motivated by an idea and a vision—not by the low bidder on a predetermined Government task.

With electromagnetic flight the only difference is that the entrepreneur requires a level of support amounting to a national commitment comparable to the space effort—a commitment that, like the space effort, cannot be justified beforehand on the basis of a clearly demonstrated need. Yet such a commitment is clearly of national concern, since the gap between what the U.S. is doing and what other countries are doing in transportation poses a serious threat to U.S. leadership in a world transportation market certain to be dominated by ground transportation for several decades to come.

Public opposition to the supersonic transport and to airport construction has made it clear that air travel has reached its limit in both speed and passenger capacity. The 7.5 square miles occupied by New York's John F. Kennedy International Airport would accommodate a 95-foot right-of-way from Washington to Boston (and newer airports are four times the size of Kennedy). The nation can no longer afford such inefficient use of land or the environmental impact of having aviation alone satisfy the society's increasing travel needs. The province of Ontario has already rejected a proposed highway system in favor of high-speed mass transportation, and a number of other countries that are not yet committed to elaborate highway or air systems will probably do likewise. Ecologically and economically acceptable high-speed mass transportation is one of the most worthwhile amenities that technology has to offer, and electromagnetic flight now appears to be the means for achieving it.



OPERATING MODEL of the magneplane is employed by the authors and their collaborators to study the motion of the vehicle and the functioning of the system for controlling propulsion. The vehicle and the guideway are 1/25 the size of a full-scale system.

HERPES VIRUSES AND CANCER

It has been known for some time that these ubiquitous viruses can cause cancer in experimental animals. There is now much evidence that a virus of this type is also implicated in some cancers of man

by Keen A. Rafferty, Jr.

The herpes viruses are among the most persistent and universal viruses found in man. They have the mysterious ability to appear and to disappear in individuals without any known route of infection or cause. One of these viruses, herpes simplex Type 1, causes "fever blisters" of the mouth and infects virtually the entire human population. Herpes simplex Type 2 is transmitted by sexual contact and causes sores on the genitals. Another common herpes virus is herpes zoster, which causes chicken pox in children and reappears as shingles in adults and also causes shingles in both children and adults. All these viruses belong to a group of viruses that have been shown to cause cancer in experimental animals. Although the herpes simplex and herpes zoster viruses apparently never cause cancer in man, there is good—albeit still inconclusive—evidence that some extremely malignant cancers in man either are caused by or are prominently associated with viruses of the herpes group. Because herpes viruses can sometimes be isolated from local infections or from tumor cells and grown in tissue culture, they may offer the best hope for proving the etiological role of viruses in human cancer. Moreover, they offer the possibility of developing vaccines to prevent certain forms of cancer, in much the same way that poliomyelitis is now prevented.

The word "virus" is from Latin and means poison or slime. It was first used in its modern sense by Louis Pasteur, who applied it to agents that were not bacteria but were nonetheless associated with disease. Although it was soon accepted that diseases could be caused by viruses, it has been difficult to obtain acceptance for the concept that cancer can be caused by viruses. This is not easy to understand in the face of unequivocal and long-standing evidence from animal experiments. In 1908 V. Ellerman and O. Bang showed that leukemia in chickens could be transmitted by injecting bacteria-free filtrates from infected chickens into healthy chickens. Three years later Peyton Rous showed that the same was true of chicken sarcoma, a malignant deep-tissue tumor. Rous received a Nobel prize for his work, but it is significant that the award was made 55 years after the original discovery.

One reason for the reluctance to accept the concept that cancer can be caused by viruses is that cancer is not contagious in the way that other viral infections such as the common cold and influenza are. Moreover, some human cancers are unmistakably associated with agents other than viruses. For example, it has been known for 200 years that chimney sweeps in England almost always developed testicular carcinoma and that the coal tar in chimney soot was the probable cause. In 1918 K. Yamagiwa and K. Ichikawa of Japan produced cancer growths by painting coal-tar derivatives on rabbit ears, thus showing that cancer could be caused by chemicals. X rays and the radiation from radioactive substances also emerged as causes of cancer. Women who were employed to paint radium on watch dials developed cancer of the lip because they pointed the tips of their brushes by putting them in their mouth. Radiologists who worked with X rays tended to develop cancer of the skin and other forms of cancer before strict safety practices were initiated. More recently resistance to the virus theory of cancer has stemmed from the difficulty of demonstrating the presence of viruses in tumors, particularly tumors of man.

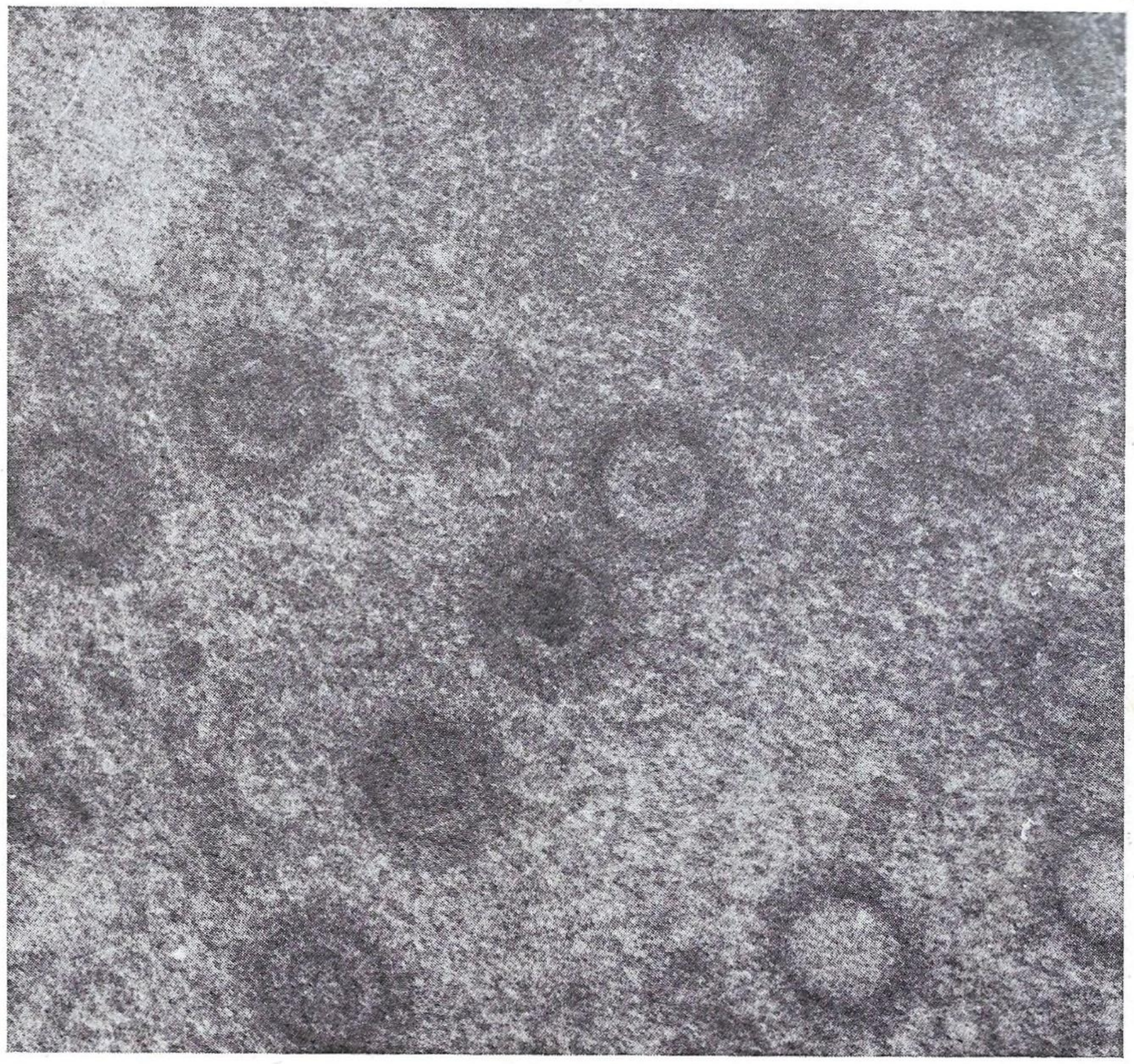
There are two main types of viruses: those containing deoxyribonucleic acid (DNA) and those containing ribonucleic acid (RNA). In animal tumors caused by RNA viruses the virus may be reproduced continually and new viruses released without damaging the host cells. RNA viruses are believed to be responsible for some human leukemias, in which white or red blood cells divide prodigiously. With DNA viruses, however, replication of the virus and its liberation from the host cell always seem to be accompanied by the death of the cell. Thus if a DNA virus were to replicate in a tumor, it would lead to the destruction of the tumor cells and the virus itself would eventually disappear.

Herpes viruses are DNA viruses. There are two other kinds of DNA viruses that are known to cause tumors. They are the adenoviruses, which are responsible for colds and other respiratory diseases, and the papova (papilloma-polyoma-vacuolating) viruses, which may be responsible for a variety of tumors (including the wart, a benign growth that can be transferred from person to person by injection of the virus).

The realization that the herpes viruses might be involved in the formation of tumors emerged from the study of the curious epidemiology of certain tumors in frogs and chickens. The leopard frog (*Rana pipiens*) is particularly susceptible to a kidney carcinoma, implying that there are special causative factors. In 1932 Balduin Lucké of the University of Pennsylvania School of Medicine began studying such tumors, and he soon discovered that the nucleus of some of the tumor cells contained large, pale, pink-staining inclusions. These inclusions could easily be seen in microscopic section. It was then believed (and still is) that inclusions of this type (Cowdry Type *A*) are caused by viruses. Lucké's finding was therefore a clear indication that the frog kidney tumor, now known

as the Lucké tumor, was the result of viral activity. Unfortunately the appearance of the characteristic inclusions was sporadic, and there was no reliable way to directly detect the viruses themselves.

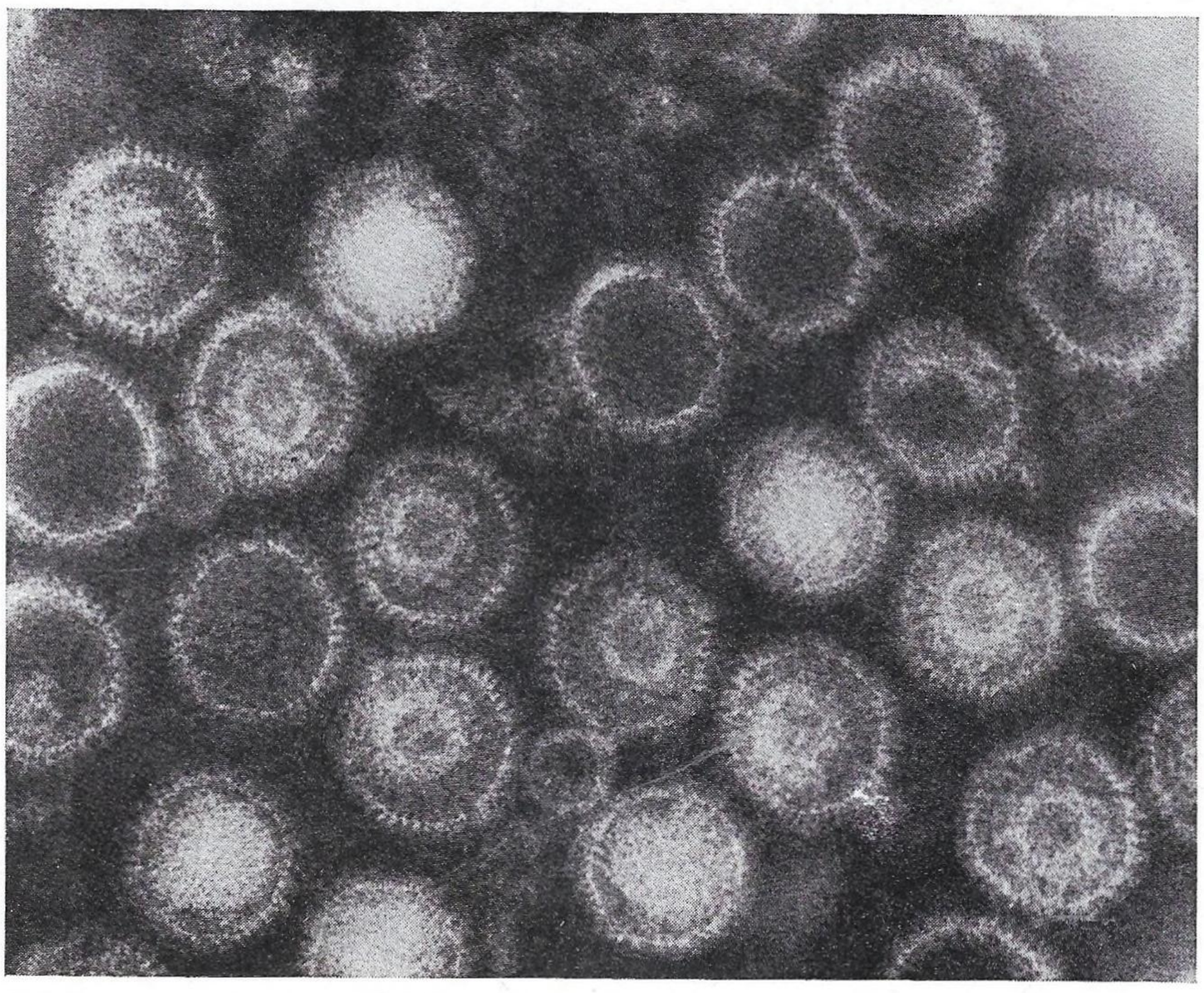
In 1956 Don W. Fawcett, who was then working at the Cornell University Medical College, made electron micrographs of Lucké tumor inclusions and found unmistakable evidence that they contained virus particles. At about the same time I began to look for similar inclusions in frog tumors. For several years, in spite of examining hundreds of laboratory-kept frogs, I was unable to find a single inclusion. Finally an accidental observation by Maria Roberts, a graduate student, suggested that the frog tumors have inclusions in the cell nucleus during the winter but not during the summer. She found inclusions in several frogs that had arrived in consecutive shipments during the winter and had been stored for a month in a cold room before being examined. On the other hand, all the tumors I had examined had developed spontaneously in frogs that had been in a warm laboratory for several months.



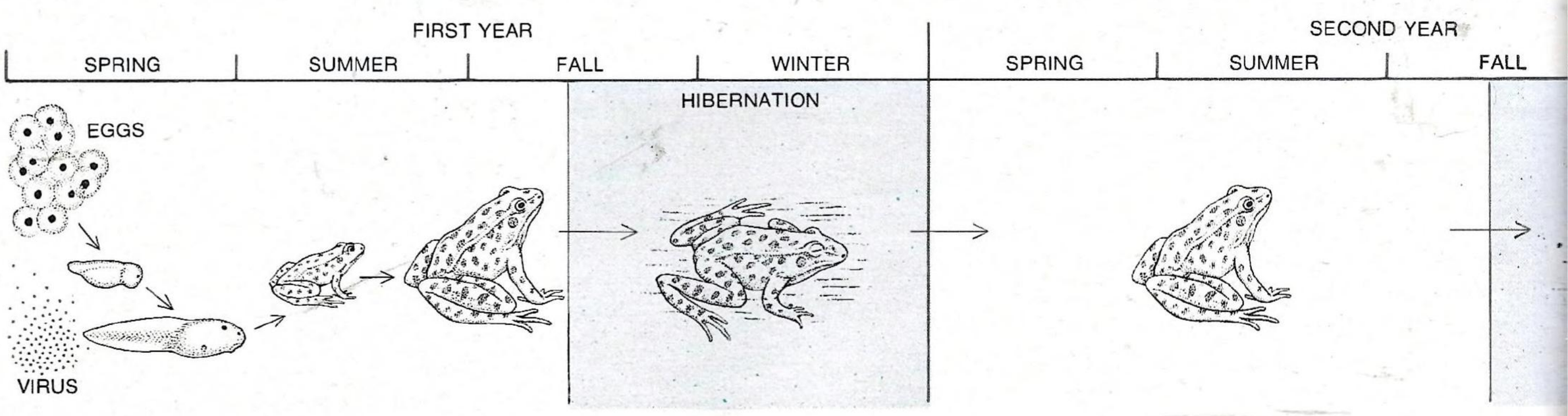
EPSTEIN-BARR VIRUS PARTICLES are seen enlarged about 160,000 diameters in this electron micrograph of a thin section of a human lymphoblast provided by M. A. Epstein of the University of Bristol Medical School. The particles are very similar in appearance to typical herpes virus particles. They have a hexagonal profile and either are empty or contain a nucleoid that is ring-shaped or dense in appearance. These virus particles were isolated from a tumor-cell tissue culture derived from a patient with Burkitt's lymphoma.

The obvious experiment was then carried out. Biopsies were made of the kidneys of laboratory frogs with spontaneous tumors. They confirmed that there were no intranuclear inclusions present. The frogs were then placed in a refrigerator for various periods of time, after which they were killed and the kidney tumors were examined. Inclusions appeared in the tumor cells, so that we were able to conclude that virus production had probably been initiated by prolonged low temperature. Further experiments indicated that the cells producing the virus died with the release of virus and that the virus appeared in the urine, a not unexpected finding in view of the location of the tumor [*see illustration on next two pages*].

Next we were able to isolate a virus from the kidney tumors by growing it in tissue cultures of frog cells. Electron-microscope observations showed that it was a herpes virus. The tissue-culture virus did not, however, produce tumors when it was injected into tadpoles. This was in spite of the fact that it had been found by K. S. Tweedell of the University of Notre Dame that cell-free extracts of actual inclusion tumors did produce tumors. Later Maneth Gravell of the St. Jude Children's Research Hospital in Memphis showed that the tissue-culture virus and the most prevalent virus in the tumor tissue have different DNA's and



VIRUS PARTICLES that are virtually identical with the Epstein-Barr particles have been isolated from a tissue culture of human nasopharyngeal carcinoma tumor cells. Particles are shown enlarged about 160,000 diameters in this electron micrograph provided by Guy de-Thé of the World Health Organization's International Agency for Research on Cancer.



LIFE CYCLE OF THE LUCKÉ-TUMOR VIRUS proposed by the author is depicted. Adult leopard frogs (*Rana pipiens*) infected with the virus often develop kidney carcinomas. The process is thought to begin when virus in the spawning water infects eggs or tadpoles. In their first and second year there is no sign of tumor growth in young frogs. In the third or fourth summer some adult frogs begin to develop kidney tumors. These "summer tumors" do not produce virus. Depending on the locale and other factors frogs that develop tumors may die during the summer or may live until the winter hibernation. During hibernation tumor growth ceases

that, although they are both herpes viruses, one is probably not derived from the other. At this point we can only speculate that two viruses are present in the tumor, or that perhaps the virus was profoundly altered in the tissue culture (an unlikely possibility), or that the tissue-culture virus was present in the original tissue-culture cells. It is also possible that the amount of virus from the tissue culture injected into the tadpoles was insufficient to induce tumors in the animals.

Recently William Collard and his colleagues at the Saint Louis University School of Medicine and at the Tulane University School of Medicine have shown that RNA from the summer-phase frog tumors and DNA from the viral inclusions in winter-phase tumors will "hybridize," that is, when fragments of the threadlike molecules of the two nucleic acids are mixed together, some of them adhere to others. This indicates that stretches of the two molecules are intimately related to one another. Since the RNA could only have been formed by being copied from the viral DNA, these results provide additional evidence that some herpes virus genetic material is present in the apparently virus-free tumor. At any rate there is little doubt that the Lucké tumor is caused by a herpes virus, although it is not yet certain which herpes virus is involved. Quite recently Robert F. Naegele and Allan Granoff of the St. Jude Hospital completed the cycle by recovering the infectious agent from a tumor that had been induced by injection of a tumor extract, and using this in turn to induce still another tumor. Thus the famous "Koch postulates" have been satisfied, and the tumor is firmly placed among those transmitted by an infectious agent.

The early experiments on frog tumors served as an important forerunner of current work on the causes of human cancers. The results obtained alerted other investigators to the prospect of discovering human tumors of herpes virus origin.

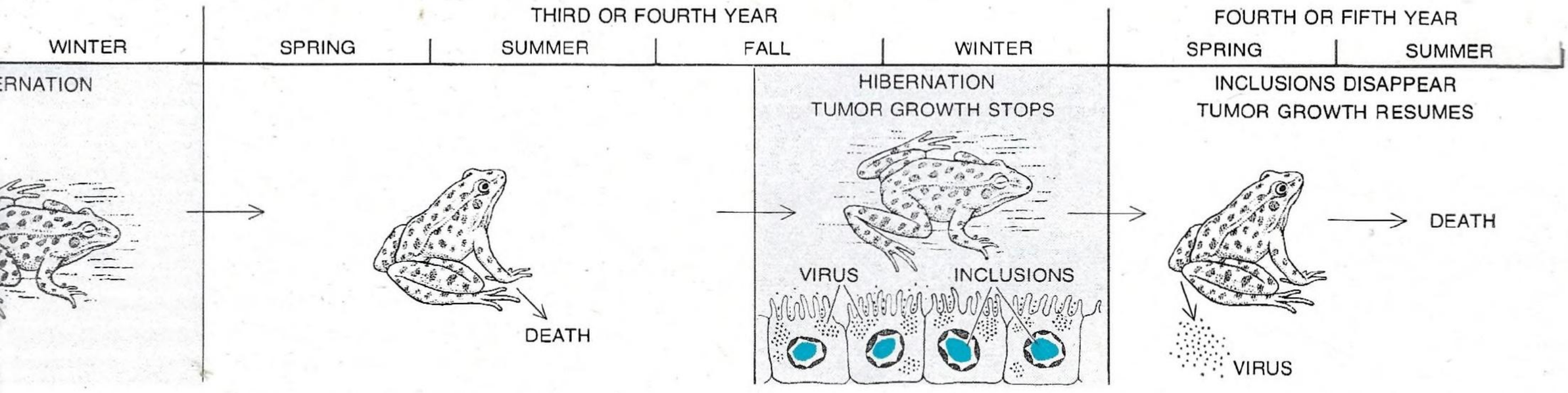
A malignant tumorous growth of the lymphoid system in chickens, known as Marek's disease, had led to the first unequivocal proof that a herpes virus is the cause of a cancer. Almost unknown a few years ago, except among a handful of academic veterinary pathologists, Marek's disease became the scourge of U.S. commercial chicken flocks in the late 1960's. At first the disease that afflicted the chickens was called polyneuritis or fowl paralysis. Later it was diagnosed as the disease that had been described in 1907 by Joseph Marek of Hungary. Marek had not recognized, however, that the disease is a malignant one. Cells of the lymphoid system become cancerous and invade the nerve cells, resulting in paralysis of the fowl. As the disease progresses other organs are invaded, and the bird eventually dies.

In 1967 several workers simultaneously demonstrated that when a cell-free filtrate from an infected chicken is injected into a healthy bird, a lymphoid tumor results. Although evidence of viruses was seen in some tumor tissue, such observations were rare. That brought up the question of how the virus was transmitted from one bird to another.

Keyvan Nazerian of the Department of Agriculture Regional Poultry Research Laboratory in East Lansing, Mich., using an antigen-antibody test, examined cells from various tissues from chickens with Marek's disease in an effort to determine how and where the virus was being released into the environment. The tumor cells seldom contained a virus, but when Nazerian examined skin sections, he found that cells of the feather follicles frequently tested positive for the presence of a virus. It was quickly shown that chicken feathers and dander (bits of sloughed-off dead skin) are highly infectious, and the route of transmission of the virus in commercial flocks seems clearly established. The virus was identified as a herpes virus. An interesting result of this work is the finding that herpes viruses are not necessarily delicate, as most viruses are. The virus causing Marek's disease is extremely resistant to drying and may remain infectious for a long time after it has been liberated in chicken dander.

An attenuated strain of the Marek's-disease virus and a related virus recovered from turkeys have both been used for live-virus vaccines, with the result that Marek's disease has been effectively eradicated in treated flocks. This suggests that cancer vaccines for man may be possible. A point worth noting is that in Marek's disease the tumor virus is not produced in the tumor cells. The virus transforms normal cells into tumor cells without necessarily producing viral progeny. Indeed, tumors that do produce new herpes viruses would probably be self-limiting, since virus production is thought to result in the death of the cell involved. It is an interesting fact that the replication of the herpes virus of Marek's disease takes place in nonmalignant skin cells that normally die in any case.

A few other animal tumors have been found to be caused by, or to be closely associated with, herpes viruses. One of them is pulmonary adenomatosis of sheep, a growth in the lungs that is responsible for substantial commercial losses among sheep raisers. A herpes virus of the cottontail rabbit was found by Harry C. Hinze of the University of Wisconsin Medical School to be capable of inducing malignant lymph tumors when



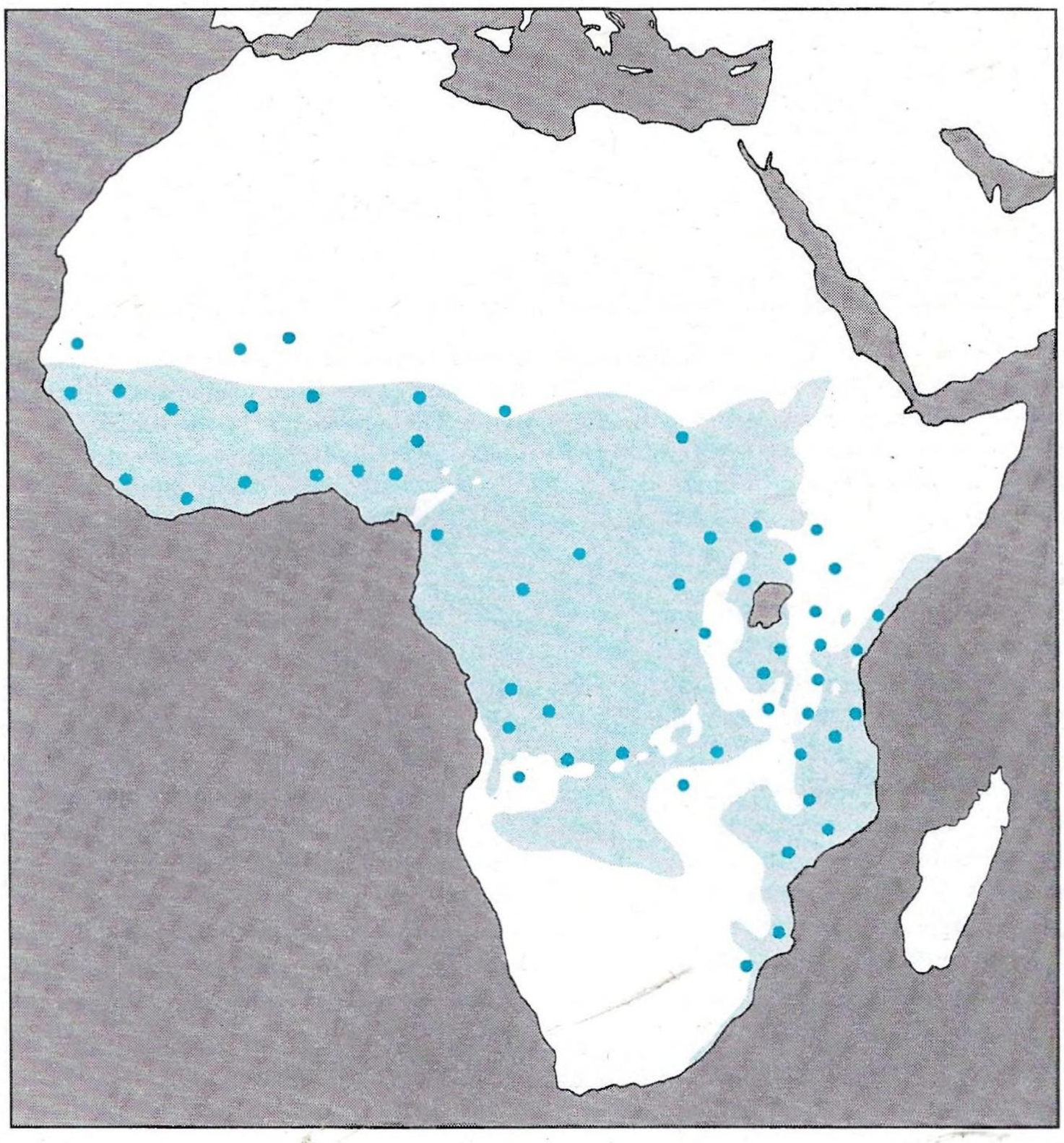
and inclusions appear in the nucleus of the tumor cells. Many of the tumor cells die, indicating that the virus has probably been activated by the low temperature and is replicating itself. The virus accumulates in the urine, and in the spring the tumor-bearing frog liberates large amounts of the virus into the spawning water with the urine it voids. In warm weather the inclusions in the tumor cells disappear, tumor growth resumes and the frog soon dies. Thus the Lucké tumor appears to be transmitted by virus that is produced in the kidney of tumor-bearing frogs that go into hibernation and then survive a winter after the tumor first develops.

it was injected into young rabbits. Both of these virus-tumor systems are being studied further.

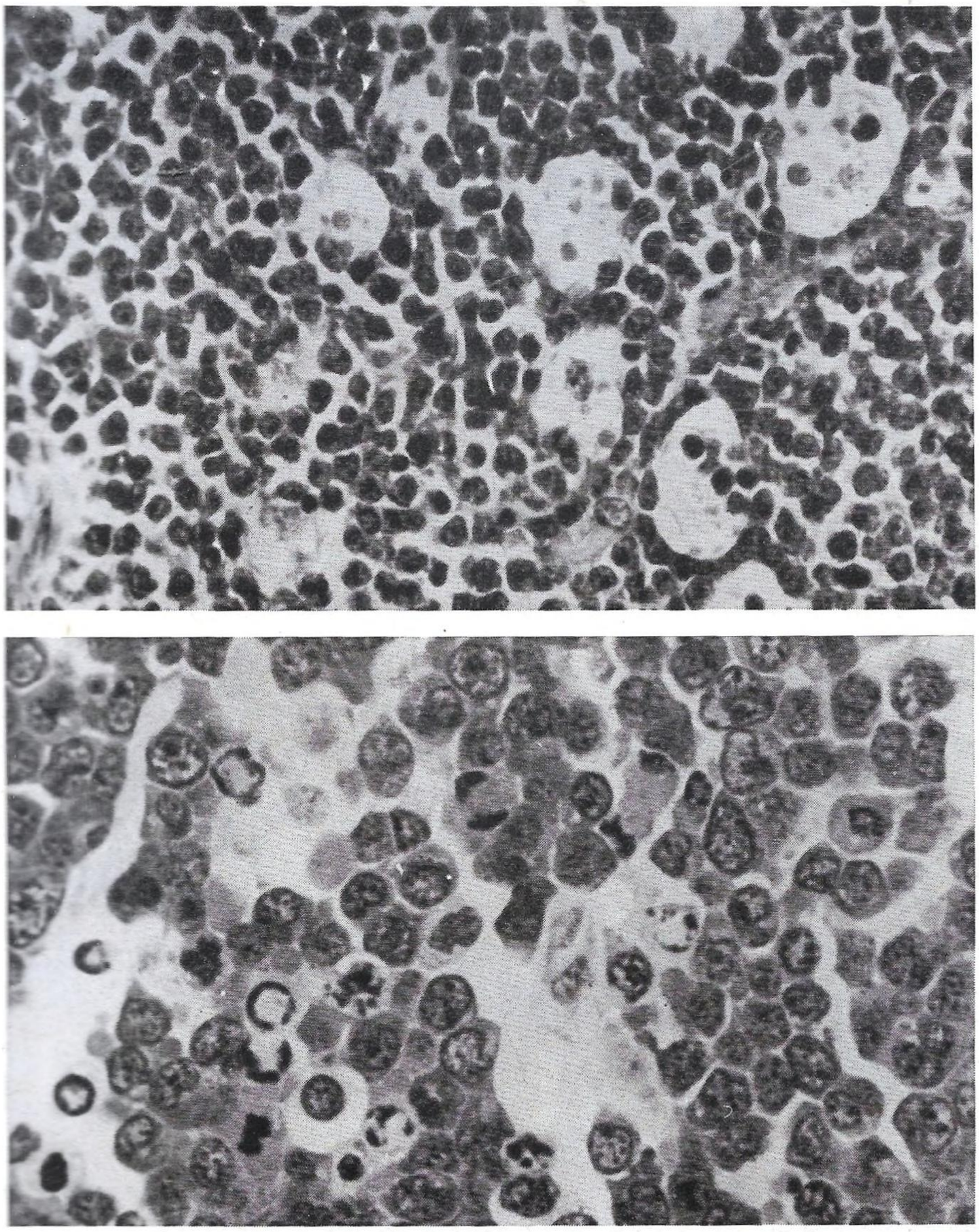
The herpes viruses that cause the Lucké tumor and the Marek's-disease tumor are both immunologically related to a herpes virus that is closely associated with a human cancer: Burkitt's lymphoma. In 1958 Denis Burkitt, a missionary surgeon in Uganda, reported that a large number of African children between the ages of four and 16 suffered from a tumor in the connective tissue of the jaw. These jaw sarcomas were thought to occur very rarely in Europe and in the U.S., but children of white missionaries stationed in Uganda sometimes acquired the disease. Burkitt also observed that all the cases came from areas in which malaria was endemic, or from areas in which temperature and rainfall conditions were such that malarial species of mosquitoes could be expected to be numerous [*see illustration at right*].

Intensive study of Burkitt's lymphoma began immediately after he published his report of this cancer that seemed to be transmitted in the same way as an infectious disease. New discoveries quickly followed. It was found that the tumor is rare in African children older than 16. One possible explanation is that exposure to some infectious agent is frequent in Uganda, so that everyone who is born in the area is likely to be exposed early in life. The adult European visitor to the area, on the other hand, may escape exposure until soon after his arrival. Moreover, a time-clustering phenomenon that had been suspected on the basis of hospital admissions was confirmed by M. Pike of the University of Oxford and R. H. Morrow, Jr., of Harvard University. For example, in Bwamba County in Uganda no cases of Burkitt's lymphoma had been reported before 1966; then seven cases were reported in 27 months and none has been reported since. Findings of this kind clearly suggest that the disease is transmitted by an infectious agent. Later K. Booth, Burkitt and their colleagues found that the lymphoma also occurs among the people of Papua and New Guinea. In both areas the conditions for malarial mosquitoes are ideal and malaria is endemic.

Although the lower jaw is most frequently the site of the tumor in Burkitt's lymphoma, tumors also arise at other sites: the upper jaw, the thyroid, the ovaries, the liver and the kidneys.



BURKITT'S LYMPHOMA IN AFRICA clusters (***colored dots***) **in those areas where climatological factors make malaria endemic. In such areas (*light color*) the altitude is less than 5,000 feet, the seasonal mean temperature is 60 degrees Fahrenheit or higher and rainfall is 20 inches per year or more. Burkitt's lymphoma is a human sarcoma of the jaw closely associated with a herpes virus. Data are taken from Denis Burkitt's original reports.**



BURKITT'S LYMPHOMA TUMOR in microscopic section (*top*) displays the characteristic "starry sky" effect of such tumors. The white "stars" are large histiocytes, cells that engulf debris from dying cells. Engulfed material is visible inside the histiocytes. A higher magnification of the tumor cells (*bottom*) reveals the empty-looking, circular structures (Type *A* intranuclear inclusions) that are characteristic of herpes virus infections. The photomicrographs were provided by D. H. Wright of the University of Birmingham.

D. H. Wright, who was then working at Makerere University in Uganda, made an intensive microscopic study of the tumor. He found that it originates in cells of the lymph nodes. Although the tumor is malignant in that it invades and destroys surrounding tissues (and ultimately causes the death of the patient unless he is treated), the cells of the circulating blood seem to remain normal, at least until the disease is in an advanced stage. This constitutes the difference between the leukemias, in which blood cells become abnormal, and the lymphomas.

Another discovery made by Wright was that microscopic sections of tumors from Burkitt's lymphoma contain histiocytes, or large, clear cells that engulf debris from dying cells of the tumor mass. It is this discovery that has helped other investigators to identify cases of Burkitt's lymphoma in parts of the world where it is rarer and less likely to arise in its most characteristic site: the lower jaw. There were some unexpected findings. With the new diagnostic aid reports began coming in that Burkitt's lymphoma occurs regularly in North and South America and in all Europe, including colder areas such as Scandinavia, where mosquito-transmitted malaria is virtually unknown. Thus it seems that if Burkitt's lymphoma is indeed transmitted as an infectious disease, it need not be transmitted by mosquitoes (and very likely never is). To keep matters in perspective it should be pointed out that even in Uganda, where the disease is perhaps commonest, the probability of developing it is one in 2,000. In the Temperate Zone the probability is far lower.

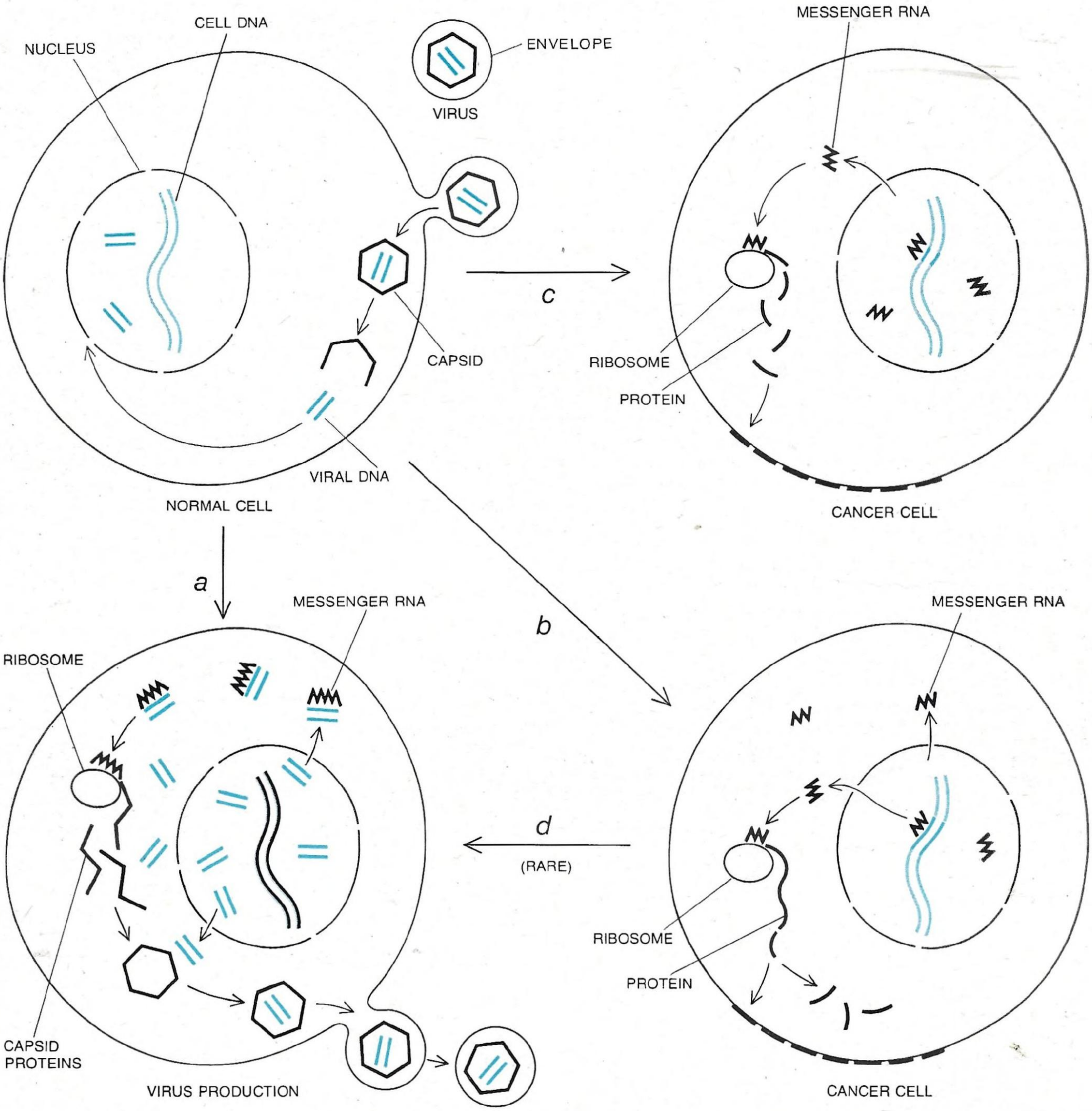
Once a virus was suspected of causing Burkitt's lymphoma intensive efforts were made to show that a virus is present in the tumor. This, however, proved to be difficult. Examination of tumor sections for virus particles with an electron microscope was fruitless, as were efforts to infect animals and tissue cultures with extracts of the tumor. Indeed, even efforts to grow the tumor cells themselves in tissue culture met with little success initially. Then M. A. Epstein and Y. M. Barr of the University of Bristol Medical School undertook to work with fresh tumor tissue flown in from Uganda, and similar experiments were begun by R. J. V. Pulvertaft, who was then working at the University of Ibadan in Nigeria. Epstein and Barr found that cells were growing in two of their cultures but that they grew in suspension in the culture medium rather than attached to the surface of the culture vessel, where tissue-culture cells normally grow. In retrospect, since lymphoma cells and other lymph-node cells periodically circulate in the blood, it might have been expected that the cells would grow in suspension. When the cells in the Epstein-Barr culture were examined with the electron microscope, herpes virus particles could be clearly seen. Pulvertaft was also able to demonstrate the presence of a herpes virus in his tissue cultures.

Epstein and Barr showed that the lymphoma cells could be propagated indefinitely in tissue culture, and that one of the cultures (designated EB-3) continually produces an infectious virus. Only about 2 percent of the cells die at any one time and liberate the virus. Other workers have shown that the virus, now called the Epstein-Barr virus or EBV, can infect normal blood cells in culture and convert them to production of the virus.

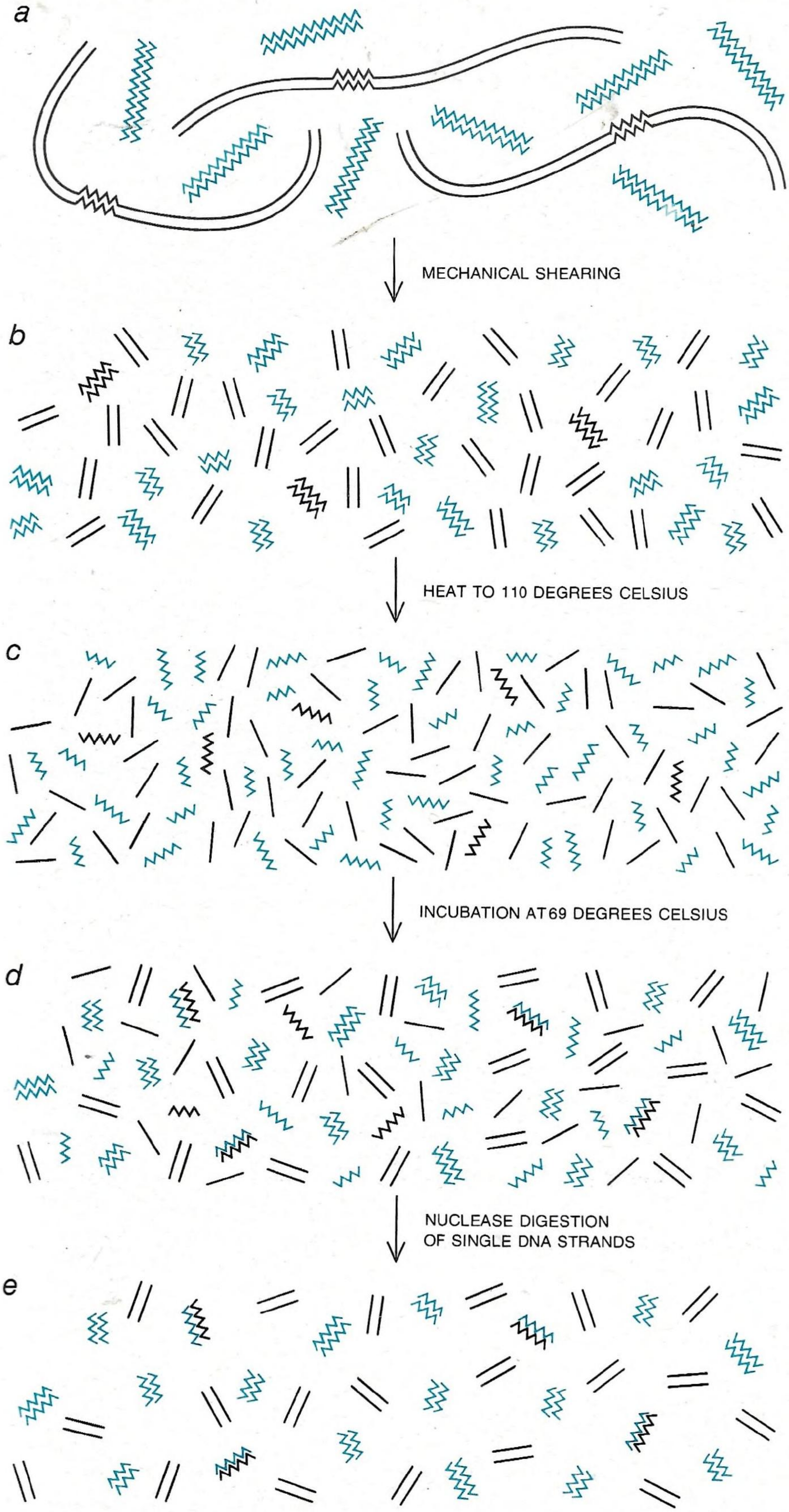
The identification of a herpes virus in Burkitt's lymphoma was significant because it is well known that some herpes viruses are quite widespread in the human population. In 1968 Werner and Gertrude Henle and V. Diehl of the University of Pennsylvania School of Medicine discovered that infectious mononucleosis, the "kissing disease" so common among American and European college students, not only is caused by a herpes virus but also cannot be distinguished from the Epstein-Barr virus, even with the most sophisticated nucleic acid hybridization or antigen-antibody tests. Therefore the two are presumably iden-

tical. This intriguing discovery was made fortuitously: a technician in the Henles' laboratory was found to have developed antibodies against the Epstein-Barr virus after she had contracted infectious mononucleosis. The Henles followed up the lead and showed that when cells from the blood of a person with infectious mononucleosis are grown in a suspension culture, they will produce a virus that is indistinguishable from the culture-grown Epstein-Barr virus.

The blood of patients with infectious mononucleosis contains dividing cells, which are never seen in the blood of uninfected people. The condition has, in fact, been described as a "self-terminating malignant disease." Microscopic examination of the dividing cells reveals that they bear a close resemblance to the proliferating white cells of acute lymphoblastic leukemia. Moreover, microscopic sections of lymph nodes from patients with infectious mononucleosis are



INVASION OF A CELL by a herpes virus normally leads to the production of new virus particles. The viral DNA replicates inside the cell's nucleus. Then some of the viral DNA moves into the cytoplasm. There it transcribes messenger RNA (mRNA), which attaches to ribosomes (*a*). Viral-coat proteins are produced and assembled into capsids, which combine with the DNA to produce a complete virus particle. The cell dies when the virus particles are released. In some instances (*b*) the complete viral DNA combines with the cell DNA. Messenger RNA is transcribed, and when this messenger RNA attaches to ribosomes, it produces proteins that are thought to migrate to the cell's surface. These protein patches on the cell's surface are believed to be involved in the transformation of the cell into a cancer cell. In rare circumstances the viral DNA in a cancer cell may revert to virus production (*d*). Another possible route for inducing malignancy (*c*) may occur when only part of the viral DNA combines with the cell's DNA. Because part of the viral DNA is lost, complete new viruses cannot be formed. Messenger RNA can be transcribed, however, and it may be responsible for the synthesis of proteins in the cell that are involved in the production or in the maintenance of a malignant state.



HYBRIDIZATION TECHNIQUE enables researchers to measure the amount of viral DNA (or RNA) present in cell DNA. Radioactive viral DNA (*colored segments*) is mixed with cell DNA (*a*). The molecules are sheared by forcing the mixture through a narrow aperture. The resulting short segments of DNA (*b*) are heated to unravel the double strands into single ones (*c*). When the mixture is cooled, some double strands re-form, enabling radioactive viral DNA to hybridize with any virus segments in the cell DNA segments (*d*). The mixture is treated with an enzyme that digests only single DNA strands (*e*). The radioactivity of the double strands is measured to determine how much DNA has hybridized.

remarkably similar in some respects to sections of Burkitt's-lymphoma tumors.

Do people who have had infectious mononucleosis have a greater probability than the general public of contracting cancer later in life? Epidemiological studies undertaken by Robert W. Miller of the National Cancer Institute and Gilbert W. Beebe of the National Academy of Sciences–National Research Council indicate that a history of infectious mononucleosis apparently is not associated with the incidence of cancer. This finding is consistent with the view of many that virtually everyone is infected with the Epstein-Barr virus, including those who never develop infectious mononucleosis.

There are a number of diseases of the blood system that seem to be prime candidates for association with, or even causation by, herpes viruses. Patients with Hodgkin's disease, a cancer of the lymphoid system, are almost always found to have high levels of antibody against the Epstein-Barr virus. Patients with acute lymphocytic leukemia also tend to show high levels of Epstein-Barr-virus antibody. In Hodgkin's disease there is a malignant proliferation of reticulum cells that, when they are viewed in the microscope, bear a striking resemblance to the histiocytic cells of infectious mononucleosis and the characteristic "starry sky" cells of Burkitt's lymphoma. Another cancer that is associated with the Epstein-Barr virus is nasopharyngeal carcinoma. Lloyd V. Old and his colleagues at the Sloan-Kettering Institute made this discovery while they were using serums from nasopharyngeal-carcinoma patients as controls in antigen-antibody studies of serums from patients with Burkitt's lymphoma.

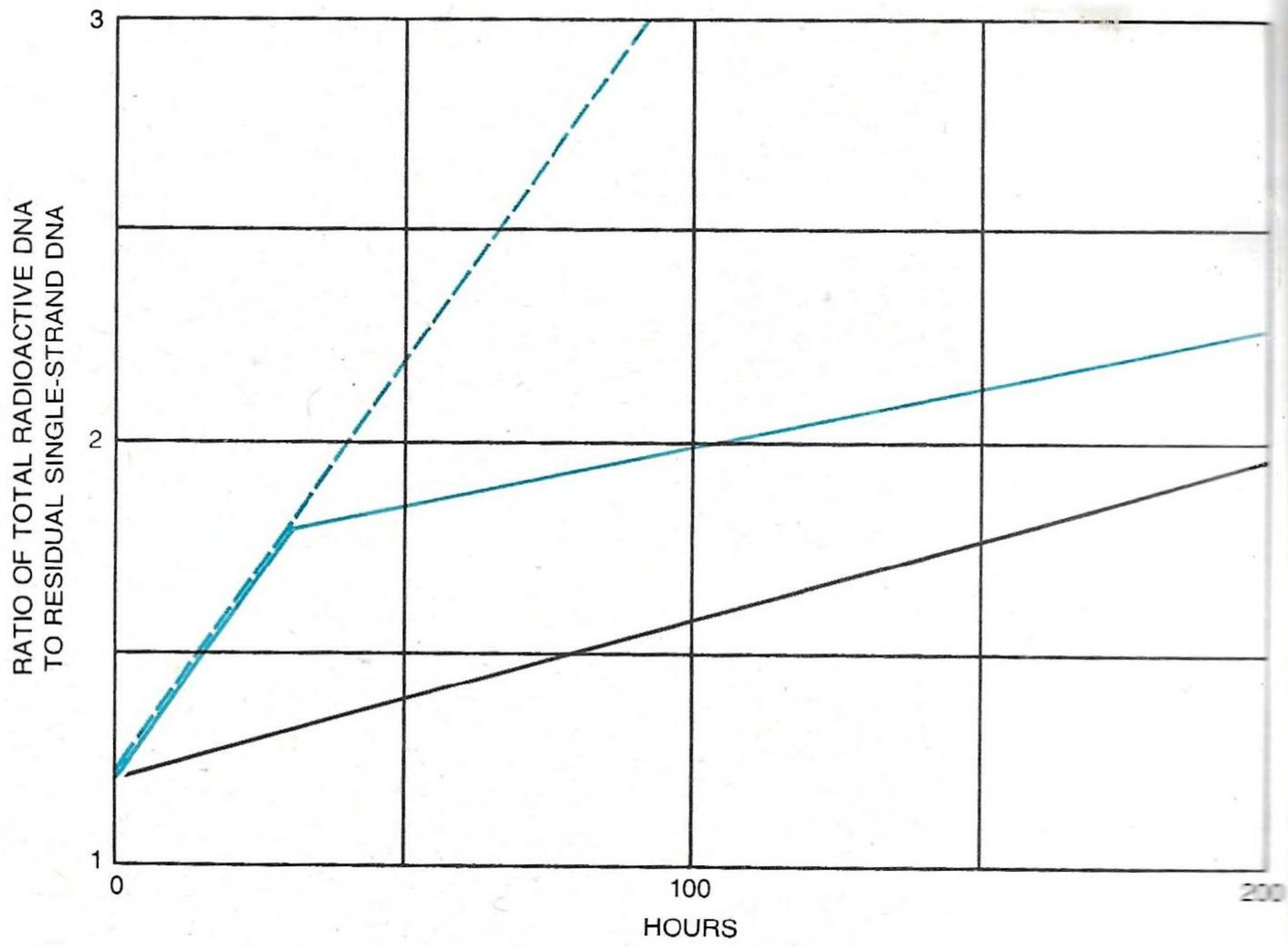
As the term indicates, nasopharyngeal carcinoma originates in the nasal cavity, the pharynx and the rear of the oral cavity. It is a true carcinoma in that the tumor consists of proliferating surface epithelial cells rather than lymphoid cells of deep tissues. Until this discovery was made only tumors of deep tissues had been associated with the Epstein-Barr virus. It is particularly interesting that a prominent structure of the upper pharynx is the tonsils, which consist of lymphoid cells covered by surface epithelium. This epithelium is perforated, and material in the mouth comes in contact with the tonsillar tissue. Clearly the lymphoid cells may become infected and transmit the infection to the epithelial cells. Furthermore, throat swabs from patients with infectious mononucleosis are a prime source of Epstein-Barr virus.

The incidence of nasopharyngeal carcinoma is extraordinarily high in certain populations. Virtually all the known cases are seen in Chinese from South China, Malaysia and Singapore. H. C. Ho of the Queen Elizabeth Hospital in Hong Kong has assembled data suggesting that the lifetime incidence in Hong Kong may be as high as one in 200. Among the "boat people" of Hong Kong the incidence is even higher. People of Chinese descent who are born in the U.S. show a lower incidence of the disease but still one that is higher than the incidence in the general population. As with Burkitt's lymphoma, nasopharyngeal carcinoma is found throughout the Western world at low incidence. Even though the data are still inconclusive, they do suggest that some cultural factor may be involved in addition to a possible viral one.

Guy de-Thé of the World Health Organization's International Agency for Research on Cancer in Lyon has grown cells from nasopharyngeal-carcinoma-tumor tissue in suspension culture. This culture produces virus particles that appear to be identical with those of Burkitt's lymphoma, but further studies are needed.

The genital form of herpes simplex (Type 2) is found in sores or reddened spots on the cervix and vaginal walls of infected women and on the penis and in the genital tract of men. Ysolina M. Centifanto and her colleagues at the University of Florida College of Medicine have found that 15 percent of men of all ages from 15 years on harbor Type 2 herpes simplex in the genital tract, for the most part in the prostate and vas deferens. The virus is seldom isolated from the female genital tract; women tend to have acute, short-lived and recurrent herpes virus genital infections. It may be that many men harbor the virus without developing the symptoms of infection but are capable of transmitting it.

André J. Nahmias of the Emory University School of Medicine has been able to establish a convincing association between the Type 2 herpes-simplex virus and cancer of the cervix, and Centifanto has described one case in which the herpes virus could be seen in the cells of tissue from cancer of the prostate. An intriguing bit of evidence comes from a study undertaken by Niza Frenkel and her colleagues at the University of Chicago, who were working with tumor tissue supplied by Nahmias. The study involved hybridization experiments with DNA from cervical-carcinoma cells [*see illustration on this page*]. They found that some DNA from Type 2 herpes-simplex virus is indeed present in these cells, but that 60 percent of the viral DNA molecule is missing. The missing portion could explain why neither the complete virus nor viral antigens can be isolated from the tumor tissue. The portion of the viral DNA that is present could become attached to the normal cell DNA and could be responsible for maintaining the cell in a malignant state. In addition the missing part would be required for the production of the complete infectious virus.



RATE OF HYBRIDIZATION is determined by measuring the amount of radioactivity in the final hybridization product over a period of time. The measurements are converted so that the vertical axis is a function of the increasing proportion of double-strand radioactive DNA present. If the cell DNA contained no viral DNA segments, the rate would be what is shown by the black curve. If the cell DNA contained complete copies of the viral DNA, the rate would rise constantly, as is shown by the broken colored curve. In a recent hybridization experiment with human cervical-carcinoma cells and herpes virus DNA, Niza Frenkel and her colleagues at the University of Chicago found that the rate rose but then dropped off, as shown by the solid colored curve. From these results they calculated that only about 40 percent of complete-virus DNA was present in cervical-carcinoma-cell DNA.

The recent discovery by Luis V. Melendez of the New England Regional Primate Research Center that the New World squirrel monkey harbors a herpes virus capable of inducing tumors in owl monkeys and marmosets is highly significant. For the first time it is possible to conduct cancer-transmission experiments on animals much more closely related to man than frogs and chickens. What is even more promising is that the resulting tumors in monkeys are similar to herpes-associated tumors in man. Unlike cultured cells infected with the Epstein-Barr virus, the cells harboring the squirrel-monkey virus (called herpes saimiri) grow on the surface of the culture vessel. This makes it easier to produce large amounts of the virus for investigation or for vaccine manufacture.

Quite recently two groups of investigators showed that the Epstein-Barr virus can induce lymphoid tumors in monkeys. One of these workers was Epstein himself, who used the virus to induce a tumor in an owl monkey. Thomas C. Shope, D. C. DeChairo and I. George Miller, Jr., of the Yale University School of Medicine induced malignant lymphomas in four cotton-top marmosets. Since such experiments cannot be performed in man, this is about as far as we can go in showing directly that a virus from human cancer is in fact a cancer-causing virus, which is a different matter from finding a virus in a tumor.

Thus the prospect is good that it will eventually be demonstrated beyond a reasonable doubt that herpes viruses can cause some forms of cancer in man. Nonetheless, an alternative explanation cannot be ignored. It is that herpes viruses are present in some human tumors merely as passengers and are not involved in the development of the tumor itself. If any human cancers are shown to be caused by a virus, there is hope that those forms of cancer can be eliminated, or at least much reduced in frequency, by the development of suitable vaccines or by finding ways to interrupt the primary routes of infection.

THE SLING AS A WEAPON

This manual missile launcher is not as well known as the archer's bow, yet it was used by lightly armed troops from India and Persia to Greece and Rome and even survived the advent of gunpowder

by Manfred Korfmann

Everyone knows that David killed Goliath with a sling, but what is the place of the sling in the history of technology? The fact is that slings were a regular weapon of warfare in Europe and the Near East at least from the Bronze Age until the 17th century of our era. Moreover, the sling has been the favored long-range weapon among numerous peoples, past and present, the world over. In Mesopotamia, in Persia and in Greece and Rome a slinger was considered a match for an archer. In that part of the world the sling had probably been known from the beginning of Neolithic times, some 10,000 years ago, and may even have been used toward the end of the Paleolithic.

David's victory over Goliath is often taken to be an allegory, but considering the nature of warfare in David's time, it might better be seen as an example both of the very real skill that slingers possessed and of the trust that they put in their weapon. A review of the encounter, as recorded in the First Book of Samuel, supports this view. David, it will be remembered, was the eighth son of Jesse. As the youngest son, he tended the family flocks. The occupation accounts for his familiarity with the sling; the weapon is used to this day by herdsmen protecting their animals. David had become harpist and armor-bearer to Saul, the king of Israel at a time when the Israelites were at war with the Philistines. The two armies had camped a short distance apart. Each day a Philistine champion, Goliath of Gath, "whose height *was* six cubits and a span," would come out of the enemy camp and offer to fight any Israelite champion and let the outcome of the single combat decide the war.

David came to the Israelite camp at a time when 40 days of Goliath's challenges had failed to rouse a single Israelite warrior. David volunteered to fight Goliath, but he refused to wear the armor or carry the arms that Saul pressed on him. At this point the narrative goes:

"And he took his [shepherd's] staff in his hand, and chose him five smooth stones out of the brook, and put them in a shepherd's bag which he had . . . and his sling *was* in his hand: and he drew near to the Philistine."

"And David put his hand in his bag, and took thence a stone, and slang *it*, and smote the Philistine in his forehead, that the stone sunk into his forehead; and he fell upon his face to the earth."

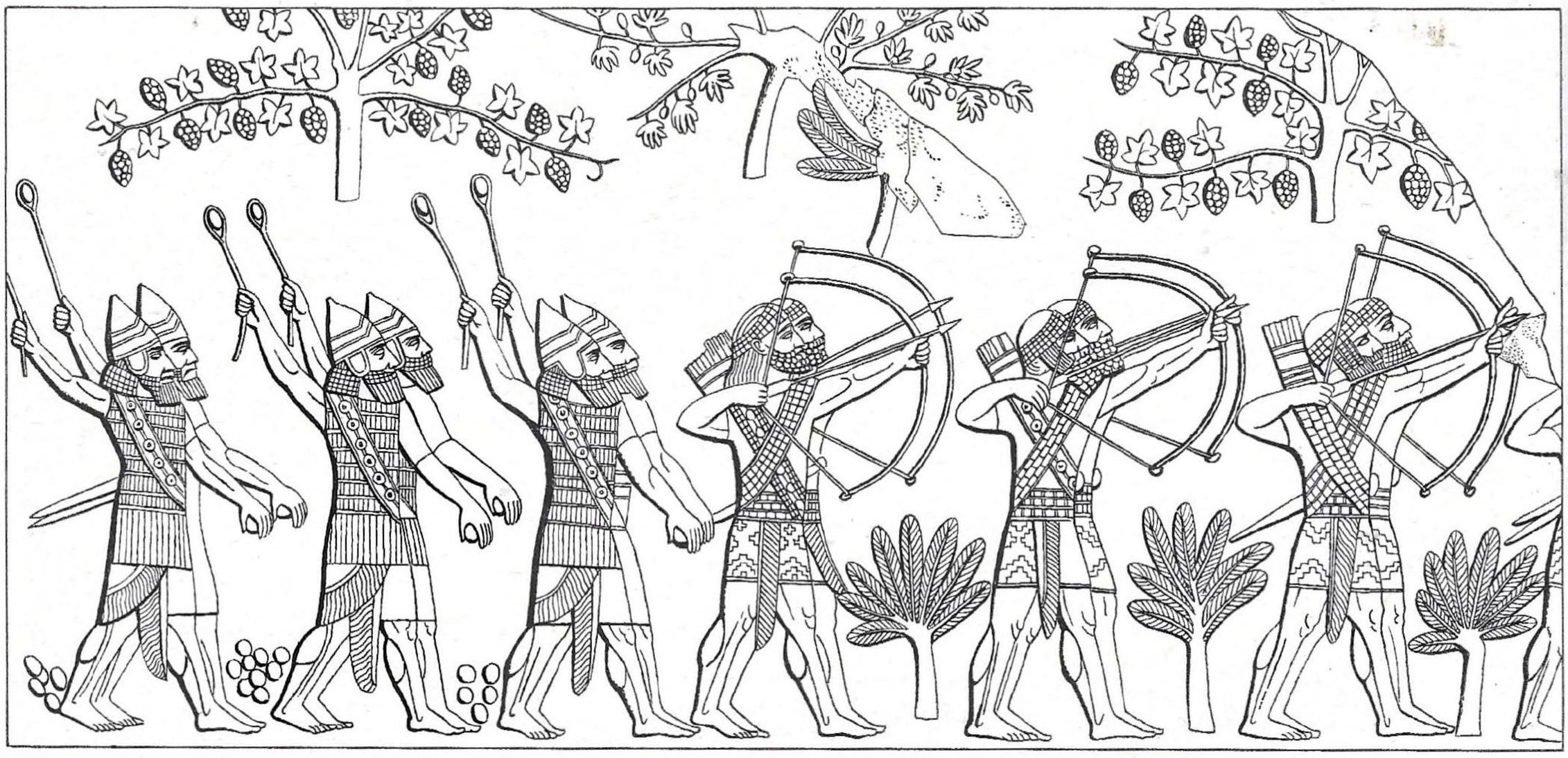
"Therefore David ran and stood upon the Philistine, and took his sword, and drew it out of the sheath thereof . . . and cut off his head therewith. And when the Philistines saw their champion was dead, they fled."

Goliath had been dressed in full armor for the encounter: a metal helmet, a coat of mail, metal greaves on his legs and a small shield slung on his back. He had a bearer who preceded him with a larger shield. The sword David used to cut off Goliath's head is not described, but Goliath's spear had a shaft "like a weaver's beam" and a heavy spearhead. This equipment is not unlike what was carried by a Greek hoplite, or heavy infantryman. It is meant for shock tactics; the spear is not for throwing but for thrusting or for defense against cavalry attack. Goliath's armor and arms, except possibly for the spear, would also have been appropriate for single combat with another warrior similarly armed. They were entirely unsuited, however, for the pursuit of an unarmored, swift-footed adversary, and so David would have been quite safe as long as he kept his distance.

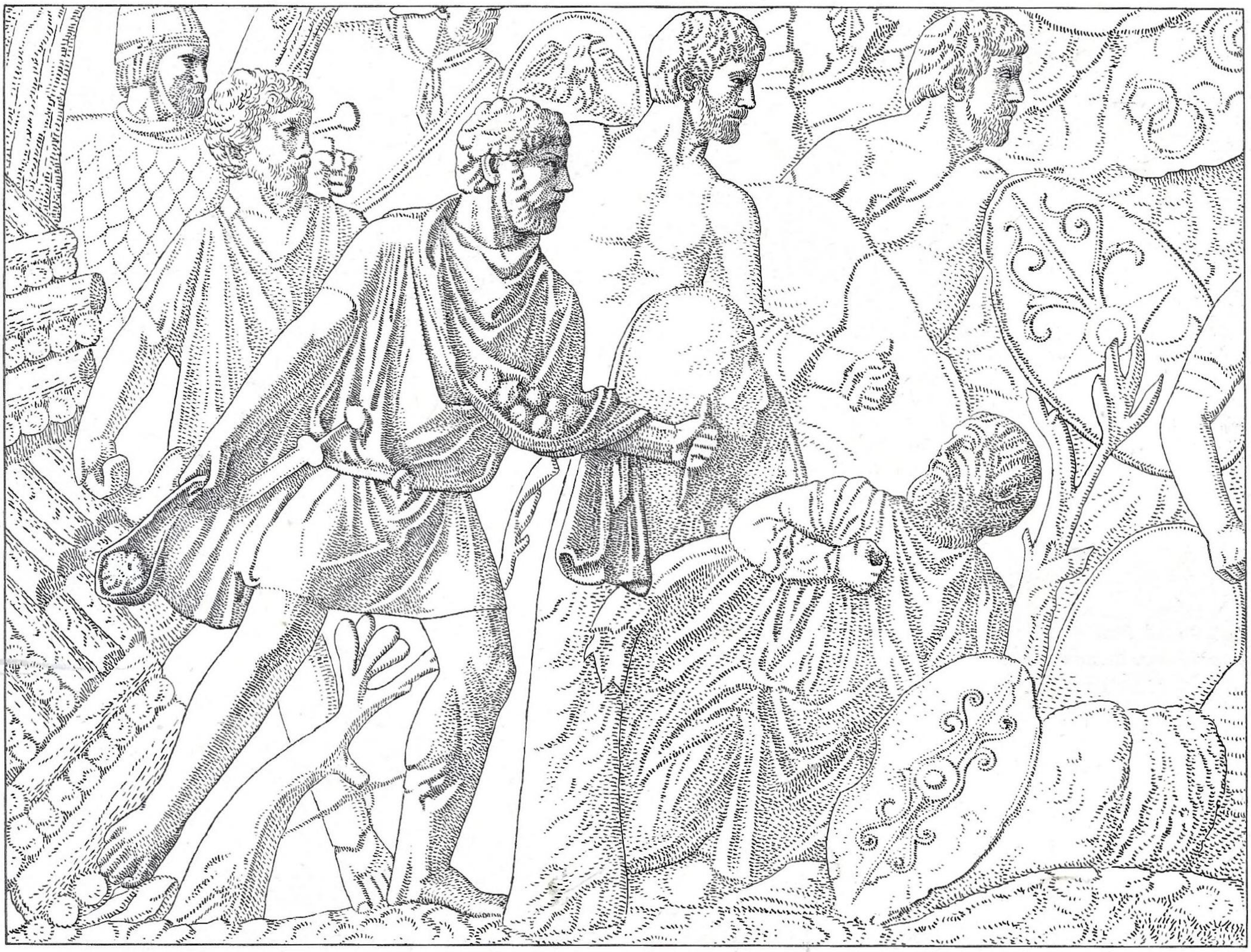
David would have had no intention of closing with his opponent; the sling is a long-range weapon. At the same time, whatever confidence David may have placed in God's help in preparing him for the encounter, he chose not one pebble for his sling but five. If his first shot had not struck Goliath in the face, the vital yet unprotected area that David had certainly aimed at, four more pebbles remained at his disposal. On balance it seems fair to credit David's victory not to divine intervention but to his skill as a slinger.

David is the best-known biblical slinger, but he is not the only one. The left-handed slingers of Benjamin (Judges) caused heavy casualties among the Israelites, and David's own elite corps "could use both the right hand and the left in *hurling* stones" (Chronicles). Why, then, has the sling remained almost unnoticed as a weapon of war? There is some hint of an answer in the *Iliad*. In Homer's account of the siege of Troy an allusion is made to the Locrians, warriors without armor who trusted in their bows and "well-twisted wool." The Greek word for "sling," however, appears only once in the entire epic. Even then the sling is mentioned not as a weapon but as an improvised bandage: one Trojan warrior binds up the wounded hand of another "with a strip of well-twisted wool . . . , the sling [used by] the shepherd of the host." It would appear that Greek peltasts, lightly armed troops whose ranks included slingers, javelin-

DAVID AND GOLIATH appear in the photograph on the opposite page as seen on the wall of a 10th-century Armenian church built on an island in Lake Van. Goliath is seen with his sword drawn. David, his long-range weapon loaded and ready, is standing much too close to Goliath in this portrayal; a cast of 250 yards was not unusual for the slingers of that time.



ASSYRIAN SLINGERS, swinging their slings parallel to their bodies, stand behind the archers in this drawing based on a relief from Nineveh showing one of the campaigns of Sennacherib (704–681 B.C.). Their place in battle suggests that they outranged archers.



ROMAN AUXILIARY in the Dacian wars, his sling at the ready, carries extra missiles in the fold of cloak flung over his shield arm. The figures in this drawing appear on a monument in Rome, the column erected to honor the Emperor Trajan's victory in the wars.

throwers and archers, received little recognition in the days when only hand-to-hand combat between armored warriors was considered honorable. Pictorial representations of hoplites (and even of archers and javelin-throwers) are common enough, but slingers are seldom seen.

Lightly armed troops nevertheless played a major role in warfare during classical Greek times. To them was given the initiation of battle. The shower of javelins, arrows and slingstones they let fly might open a breach in the opposing ranks; at the least it would expose weak points in the enemy formation that the advancing heavy infantry could exploit. Moreover, if the advance was unsuccessful, the lightly armed troops were available to cover the heavy infantry's retreat. An army that entered battle without peltasts was as good as defeated.

We have a detailed account of the fate of just such an army; it had been deprived overnight of almost all its lightly armed troops. This was the force of 10,000 Greek heavy infantrymen that was the backbone of a much larger army seeking to overthrow the king of Persia in 401 B.C. After the pretender to the throne who led them had fallen at the Battle of Cunaxa, the pretender's native forces fled and the Greeks were left alone. The Athenian Xenophon undertook to lead the 10,000 Greek infantrymen to safety, but on their first day's march they were so plagued by small numbers of enemy cavalrymen, archers and slingers that they could travel only some 25 stadia: less than three miles. That night Xenophon declared to his captains: "We need slingers ourselves at once, and horsemen also."

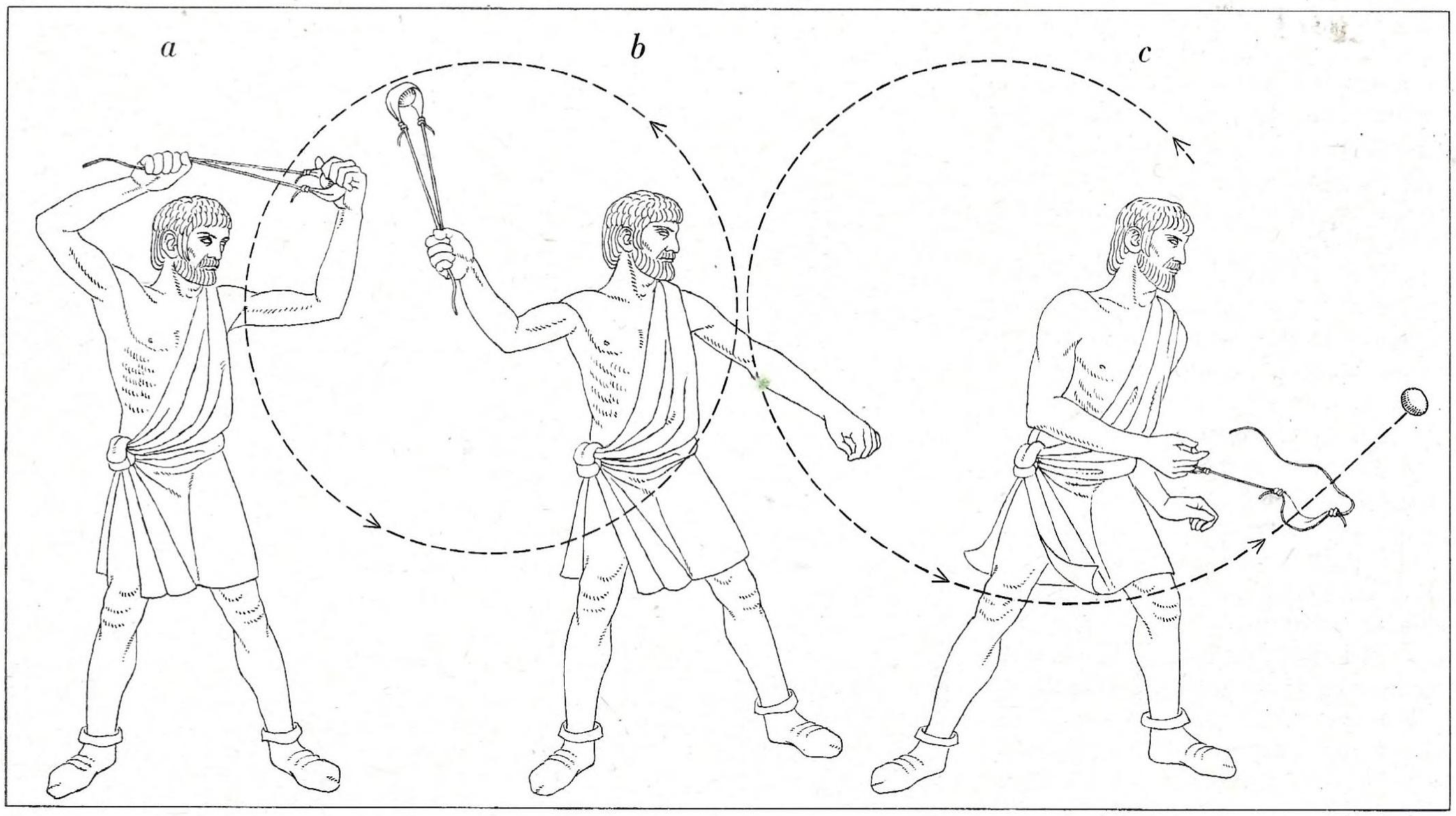
"Now, I am told," Xenophon continued, "that there are Rhodians in our army, that most of them understand the use of the sling, and that their missile carries no less than twice as far as those from the Persian slings. For the latter have only a short range because the stones that are used in them are as large as the hand can hold; the Rhodians, however, are versed also in the art of slinging leaden missiles."

STARTING POSITION, with sling poised above the head, is seen in this sculpture of a Neo-Hittite slinger from Tell Halaf in Syria, executed in the ninth or eighth century B.C.

Xenophon and his colleagues soon recruited from the ranks 200 slingers and a cavalry squadron of 50 men mounted on packhorses. The addition of these lightly armed forces to a body of 200 Cretan archers among the 10,000 enabled the Greeks thereafter to give a good account of themselves against the pursuing Persians. The Cretan archers' range was not the equal of the Persian archers', but the Rhodian slingers, Xenophon noted, "carried farther with their missiles than the Persians, farther even than the Persian bowmen." Considering that the archers of Persia were then regarded as the best in the world, his statement speaks well for the range of the Greek slingers.

Exactly how do the sling and the bow compare in range? The Roman military commentator Vegetius, writing in about A.D. 400, recommended target practice with the bow at a range of 180 meters. Even a modern sporting bow with a 45-pound pull can propel its arrow little more than 200 meters. With a long, light "flight arrow" and a bow with a 60-pound pull an archer trying for distance might achieve a range approaching 275 meters. By way of comparison I asked some young men in eastern Turkey to sling ordinary pebbles for me. In five out of 11 trials the pebbles struck beyond a mark placed 200 meters away, and the three best casts fell between 230 and 240 meters away. None of the young men appeared to be a skilled slinger; at least none had a sling in his possession at the time. Moreover, the missiles were pebbles selected at random rather than the carefully shaped stone, clay or lead missiles launched by slingers in Greek and Roman times. On the basis of Xenophon's comment alone it seems probable that a slinger casting lead missiles could attain a range in excess of 400 meters.

The sling I have been discussing is the flexible hand sling (*funda* in Latin). There is a second kind of sling: the staff sling (*fustibalus* in Latin). The hand sling can be no more elaborate than a strap three feet or so in length and an inch or



HAND SLINGER'S CAST begins (*a*) with the sling loaded and poised; the fixed end of the sling is looped around one finger of the slinging hand and the free end is held between thumb and forefinger. Three or four counterclockwise rotations of the sling (*b*), achieved primarily by the movement of wrist rather than arm, bring the missile up to maximum velocity. The missile is let go (*c*) when the slinger releases the free end of his sling; at the start of its parabolic flight it travels at more than 60 miles per hour.

so in width. At one end the strap is looped, knotted or tasseled, allowing it to be made fast to any of the four fingers of the slinger's throwing hand. The other end, which can be knotted to provide a grip, is held between the thumb and forefinger of the throwing hand. The thrower places the missile in a "pocket," sometimes artificially enlarged, at the end of the dangling loop. If the missile is made of stone or clay, it is usually the size of a small egg. A rotary motion of the wrist sets the sling whirling rapidly, either semihorizontally (around the slinger's head) or vertically (parallel to the body). After three or four revolutions the slinger releases the free end of the strap and the missile flies off on a tangent to the circle described by the sling.

The staff sling is inferior in range to the hand sling. At the same time it is easier to handle and can be employed to throw larger and heavier missiles. The sling, usually made of cord, has one end tied to a pole perhaps three feet long. The free end of the sling is temporarily attached to the end of the pole; either the end of the pole is notched so that the free end of the sling can be slipped into the notch or the free end of the sling is looped so that it can be slipped over the end of the pole. An enlarged pocket at the end of the dangling loop holds the missile. The pole, which at first is held parallel to the ground, is brought abruptly upright above the slinger's head; at the top of the swing the free end of the sling slips off and the missile flies free [*see illustration on opposite page*]. Used in both Greek and Roman times, the staff sling was a popular siege weapon through the Middle Ages. Even with the advent of gunpowder it served as a kind of grenade launcher well into the 17th century.

The longer the sling, within practical limitations, the greater the potential velocity of the missile. The natives of the Balearic Islands to the east of Spain were notable slingers. Indeed, Polybius, a Greek historian of the second century B.C., stated that the islands took their name from this fact, *ballein* being a Greek word meaning "to throw." However that may be, Balearic slingers served as lightly armed troops in many of the wars of classical times, perhaps most notably in the long conflict between Rome and Carthage. They always carried three lengths of sling: a long one for long range, a short one for short range and one of intermediate length for ranges in between.

Turning to the missiles themselves, it is clear that when they are nothing more than water-worn pebbles, the archaeologist cannot easily identify them as missiles. Only when a number of similar stones are found close together and show no evidence of being used for some other purpose (say hammering or rubbing), or best of all when they are of a kind that is foreign to the place where they are found, can such stones be considered potential evidence for the use of the sling at that place and at the time indicated. Fortunately, although vast numbers of naturally formed missiles may never be recognized, a good many ancient sling missiles were manufactured with great care. These artifacts are not always easy to perceive. Even when they have been recognized, they have often only led archaeologists to wonder what purpose such odd "clay eggs" may have served.

In the Near East the first manufactured sling missiles were spherical. They made their appearance shortly before the beginning of the sixth millennium B.C. Biconical projectiles were the next to appear [*see top illustration on page 40*]. A millennium later, around 4000 B.C., ovoid missiles also came into service. Three considerations, all concerned with the improvement of accuracy, seem to have worked together in the development and standardization of the missiles. The first objective was to make the weight of the missiles reasonably uniform, so that the slinger did not have to compensate for a different weight at every cast. The second objective was to provide a uniform, somewhat stream-

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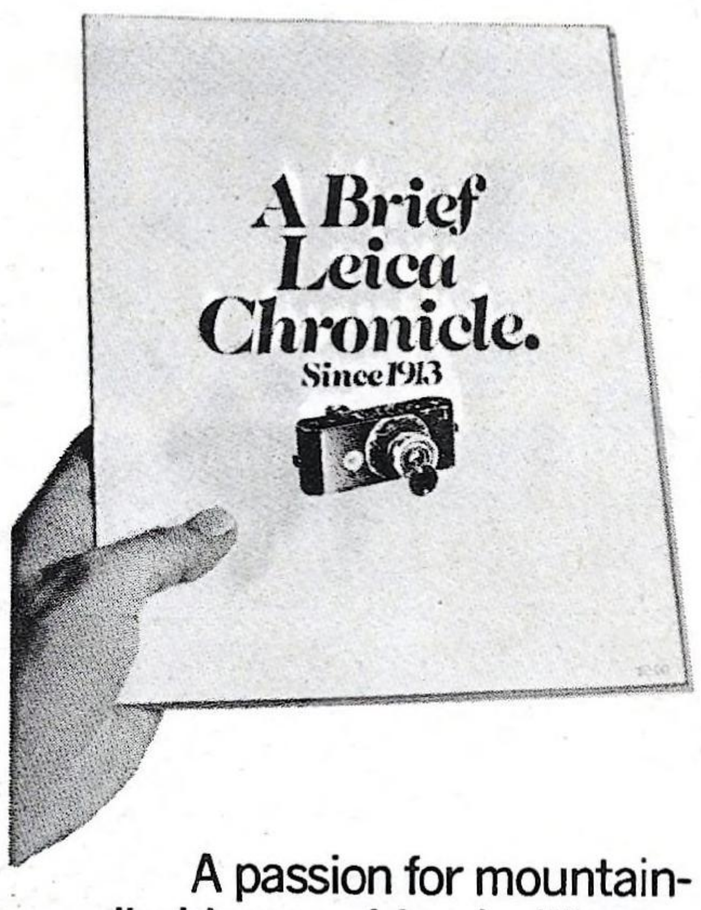

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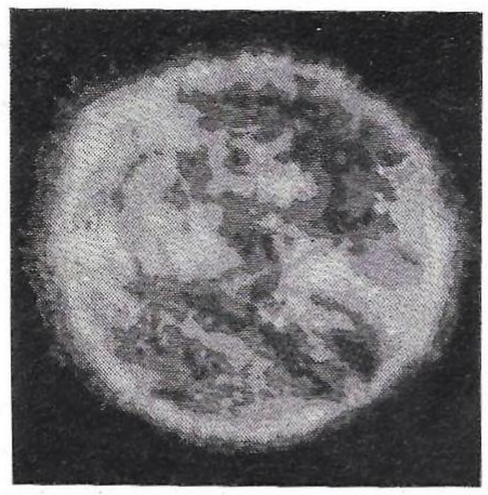

THE COVER

The colorful pattern on the cover is a spectroheliographic diagram of the sun in the extreme ultraviolet region of the spectrum. The diagram was constructed from measurements made by a spectroheliograph put aboard Orbiting Solar Observatory VI by the Harvard College Observatory Solar Satellite Project (see "The Solar Corona," page 68). The instrument isolates a single wavelength in the spectrum of the sun and the inner corona. Here the wavelength is 625 angstroms, the spectral line of magnesium stripped of nine electrons at 1.3 million degrees Kelvin. The deep red regions in the picture are the coolest and the white regions are the hottest. Spectroheliograms made in the spectral lines of elements of higher and higher ionization reveal the structure of hotter and hotter regions of the corona.

THE ILLUSTRATIONS

Cover courtesy of Harvard College Observatory Solar Satellite Project

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25	Milford Small
27	M. A. Epstein, University of Bristol Medical School (*top*); Guy de-Thé, International Agency for Research on Cancer (*bottom*)
28–29	Tom Prentiss
30	D. H. Wright, University of Birmingham
31–33	Tom Prentiss
34	W. Schiele, Deutsches Archäologisches Institut, Istanbul
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68	Harvard College Observatory
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71	High Altitude Observatory, Boulder, Colo. (*top*); Mees Solar Laboratory, University of Hawaii (*bottom*)
72	Allen Beechel
73	Harvard College Observatory, Imperial College of Science and Technology, York University and Science Research Council Astrophysics Research Unit at Culham Laboratory
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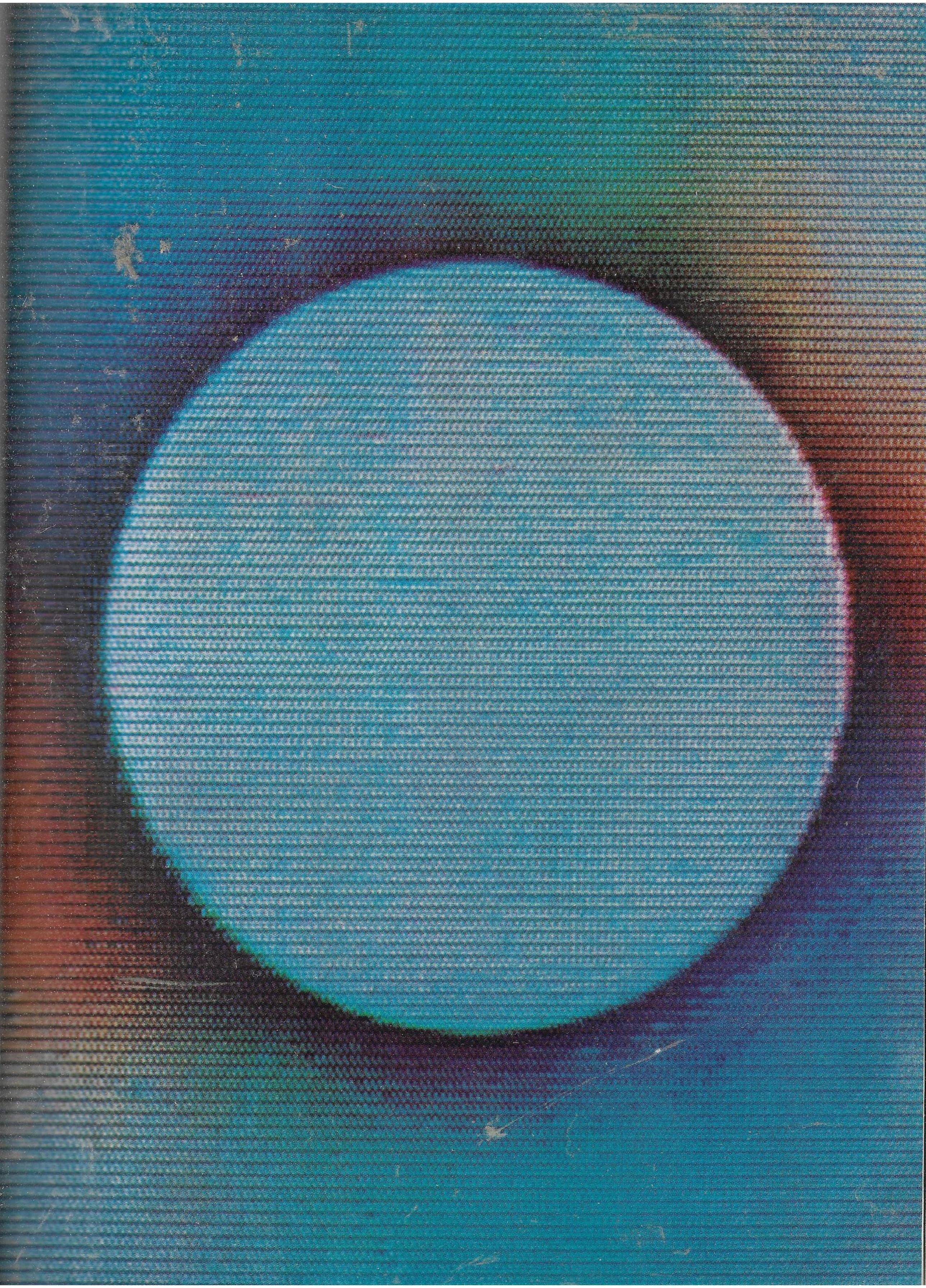


THE SOLAR CORONA

The physical nature of the sun's outer atmosphere is emerging from observations made not only on the ground during eclipses but also from rockets, from satellites and even from the moon

by Jay M. Pasachoff

The brilliant visible disk of the sun, the photosphere, obscures some of the sun's most interesting features. During a total eclipse of the sun, such as the unusually long one of this past summer, the photosphere is neatly masked and some of these features can then be seen. One of them is the chromosphere, the irregular level of the sun's atmosphere just above the photosphere. During a solar eclipse, for just a few seconds at the beginning and at the end of totality, the chromosphere is visible as a pinkish glow at the advancing edge of the moon. The red color results from the fact that the chromosphere emits strongly at the single wavelength in the hydrogen spectrum designated hydrogen-alpha. When even the glow of the chromosphere is extinguished by the moon, there emerges the pale splendor of the sun's outer atmosphere: the corona. Until this century the corona was as mysterious as it was awesome. In recent decades it has gradually been revealing its nature to telescopes and computers on the ground and to instruments in rockets, in satellites and even on the moon.

The corona is a million times fainter than the photosphere. Ordinarily it is concealed from observers on the earth by the everyday blue sky. In principle one should be able to see it simply by blocking out the sun's disk with one's thumb. In reality the light scattered in the sky near the sun is still too intense for the corona to be seen. It is fortunate for astronomers that they have a lunar thumb. The moon is 400 times smaller than the sun, but it is also 400 times closer to the earth. It therefore has almost exactly the same angular diameter in the sky as the solar photosphere: about half a degree.

The moon's orbit is nearly in the plane of the ecliptic (the plane of the earth's orbit around the sun). Each month it comes close to the sun in the sky; its far side (with respect to the earth) is lighted and its near side is dark. In this position it is called the new moon. The lunar orbit is tilted slightly from the ecliptic, so that the moon usually passes above or below the sun. Two to five times a year, however, the moon passes in front of the sun. Sometimes the conical shadow of the moon falls slightly off to the side of the earth and all that is seen is a partial eclipse. At other times the moon is at a relatively distant point in its elliptical orbit around the earth and consequently has a smaller angular diameter than the sun. During such an eclipse an observer sees a ring of sunlight around the dark moon; the eclipse is called annular, after the Latin *annulus*, meaning ring.

As long as the smallest fragment of photosphere remains in view so much light is scattered by the earth's atmosphere that the corona remains hidden. When the moon is close enough, however, and is properly centered over the disk of the sun, the lunar shadow sweeps across the earth in a band as much as 170 miles wide and thousands of miles long. From any point in this path of totality the corona is visible for a period that can be as short as a split second or as long as the theoretical maximum of seven minutes 40 seconds, depending on the conditions of the individual eclipse and where in the path the observer is standing.

Astronomers have had to travel all over the world to carry their equipment to a favorable spot in the path of totality. An instrumental malfunction at the crucial time can spoil the results of months of preparation. The weather is always a major factor; many expeditions have been ruined by rain or overcast, or even by a stray cloud obscuring the sun at the wrong moment. Eclipses have attracted expeditions most recently to southern Mexico on March 7, 1970, to Canada and Alaska on July 10, 1972, and to Africa on June 30 of this year. From the information gathered on many such expeditions a consistent picture of the corona has emerged that is now generally accepted.

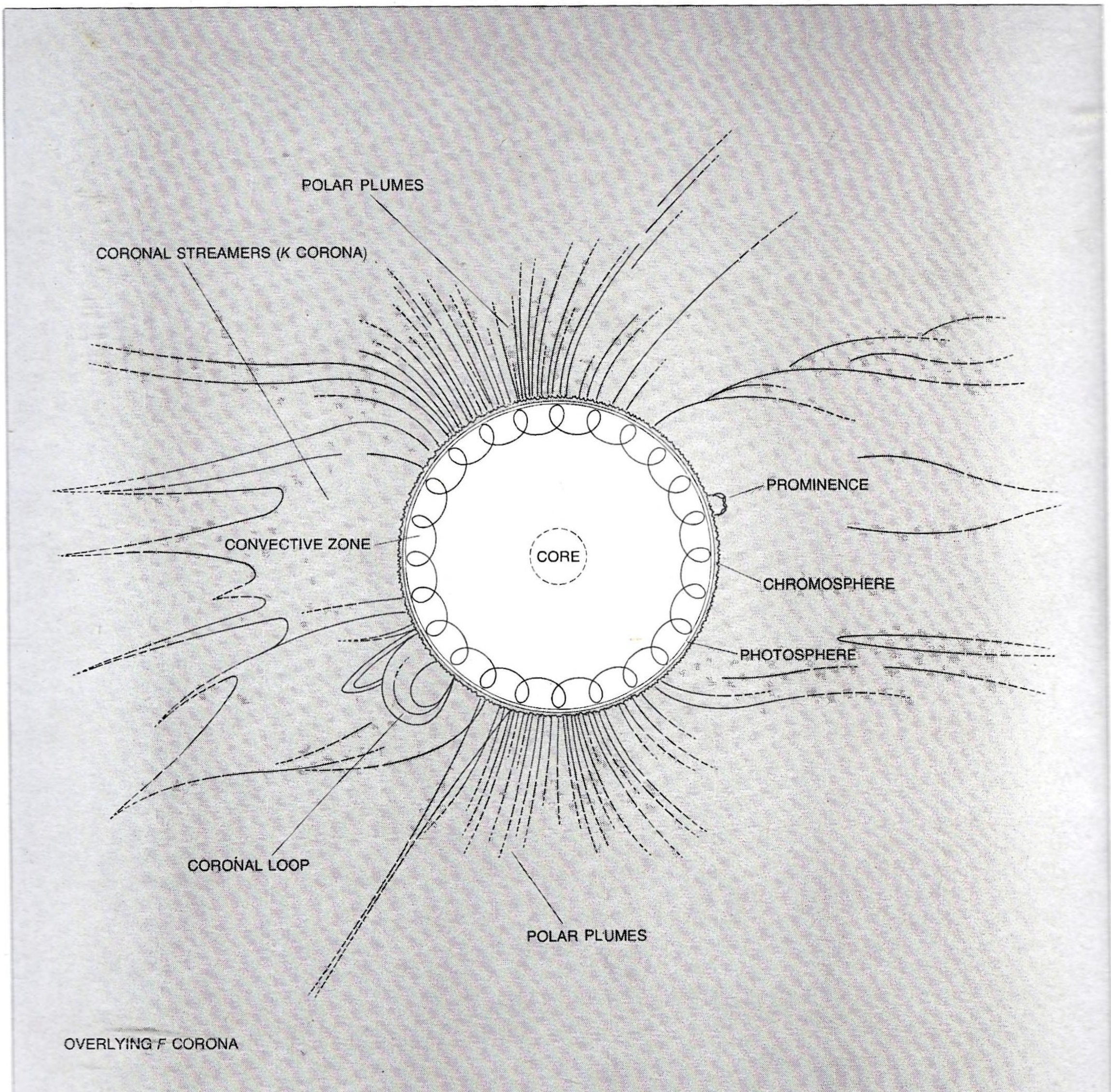
The corona that is seen during eclipses has three major components. The first, which is visible most clearly as the inner corona, extends about two solar radii out from the center of the sun: perhaps 1.4 million kilometers. It is made visible by photospheric light scattered by the electrons in the gas surrounding the sun. Its spectrum is continuous, that is, it does not show the dark absorption lines in its spectrum called Fraunhofer lines, which represent the wavelengths of light ab-

POLARIZATION OF THE CORONA is revealed on the opposite page in a color image synthesized by computer. Donald H. Menzel of the Harvard College Observatory and the author photographed the corona through polarizing filters during the total eclipse of the sun of March 7, 1970, at Miahuatlán in Mexico. The pictures were scanned photoelectrically and the information about the direction and amount of polarization from each one was stored in the computer memory. Lynn H. Quam and Robert B. Tucker of the Stanford Artificial Intelligence Laboratory used the computer to combine the information from the photographs and to generate a three-color display on a television screen. The hue corresponded to the direction of polarization and the saturation to the degree of polarization. The corona is polarized radially outward from the surface of the sun. On the synthesized image this is indicated by the fact that the colors of the corona are complementary at 90-degree intervals.

sorbed within the photosphere. This component of the corona is called the *K* corona, from the German *Kontinuum.*

At about two solar radii the *K* corona is less dominant, and radiation is added by sunlight scattered by the dust that is distributed through interplanetary space. In its spectrum this second component of the corona shows the dark Fraunhofer lines and is therefore called the *F* corona. The *K* corona continues out into space along with the *F* corona, although it gets fainter with increasing distance from the sun. It extends even past the orbit of the earth, although at such distances it is of course extremely thin. Thermal radiation from the dust has been observed in the far-infrared.

The third major component of the light of the corona is revealed by emission lines in the spectrum of highly ionized atoms near the sun: atoms stripped of as many as half of their constituent electrons. Although this radiation is very weak and makes a negligible contribution to the total intensity of the corona, it yields detailed information



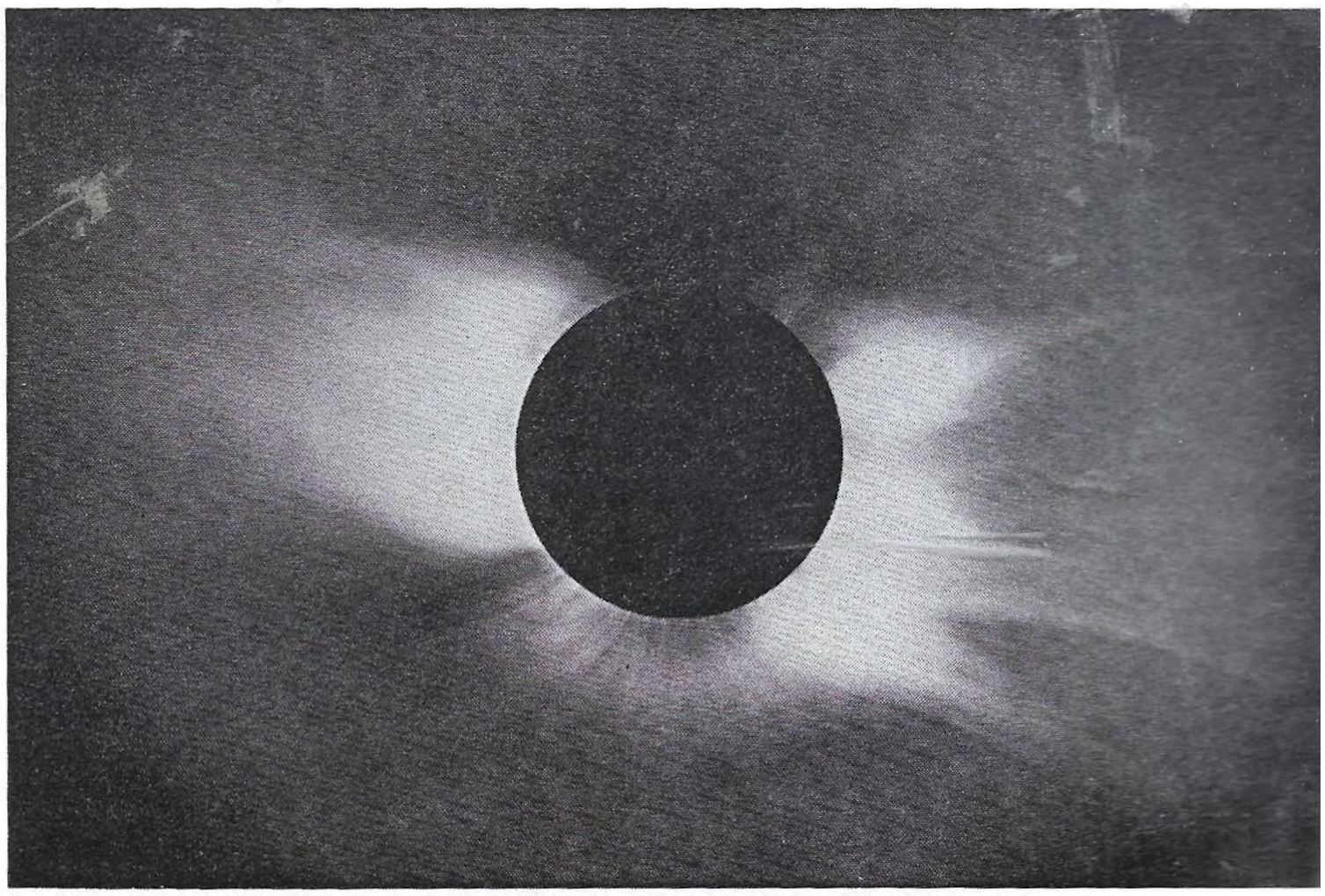
STRUCTURE OF THE SUN and the corona is summarized in this cross-sectional diagram. Energy from thermonuclear reactions in the core makes its way gradually to the sun's exterior layers. Most of the visible light received on the earth comes from the photosphere. Just under the photosphere is the convective zone. Shock waves from the convective zone carry energy up into the chromosphere and the corona. The temperature of the sun is at a minimum in the photosphere and lower chromosphere; the shock waves cause the temperature to rise through the upper chromosphere and the corona until it reaches some two million degrees Kelvin in the corona. From the corona the solar wind expands into interplanetary space. The visible corona has three major components. The first is the *K* corona: light scattered by the electrons in the gas surrounding the sun. The second is the *F* corona: light scattered by the interplanetary dust between the sun and the earth. The radiation of third component is emitted by highly ionized atoms near the sun.

about the physical conditions inside the corona.

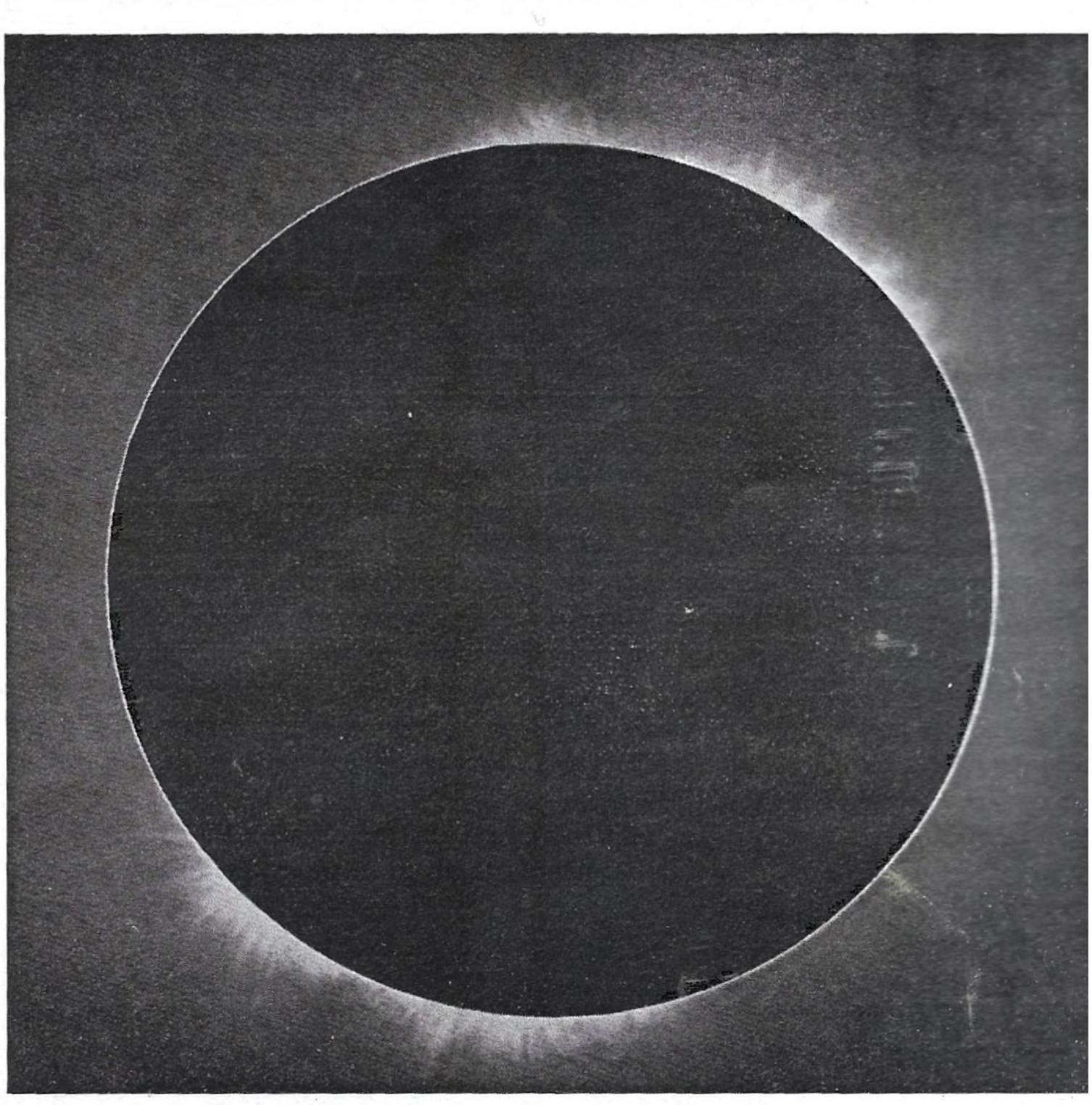
The corona has a temperature of about two million degrees Kelvin. Many lines of physical argument now lead to this result, although how the corona could have such a high temperature was one of the major questions in solar physics for many years. The continuous spectrum is a strong clue. Two million degrees is a kinetic temperature: it is an indication that the electrons are moving so fast that the wavelengths of photospheric light each one scatters is Doppler-shifted. The shifts are very large because of the high temperature and are completely random, so that they wash out all the absorption lines from the photospheric Fraunhofer spectrum. Historically this was the first reasoning that explained the continuous nature of the spectrum of the *K* corona. Only when the emission lines in the coronal spectrum were identified with the radiation from highly ionized atoms, however, were solar astronomers convinced that the coronal temperature was indeed high.

More than 60 chemical elements have been detected in the sun. Their abundances in the corona are now known to be essentially the same as the abundances in the photosphere. Two of the strongest lines in the visible region of the spectrum are the green line at a wavelength of 5,303 angstroms and the red line at 6,374 angstroms. The first line is emitted by iron atoms stripped of 13 of their 26 electrons by the extreme temperatures; it is designated Fe XIV. The second line is from iron atoms stripped of nine electrons; it is Fe X. (The un-ionized species of an element is labeled with the Roman numeral I, the first ionized state by II, and so on.) Two emission lines in the near-infrared are stronger: the lines of Fe XIII at 10,747 and 10,798 angstroms. These lines, however, lie in a relatively unexplored spectral region where photographic film is not sensitive. During the eclipse in June, J. Philip Schierer of Tektronix, Inc., and I used a new electronic spectrometer to observe these lines. Although my results are still preliminary, they do show the value of using devices such as silicon-diode Vidicons for the near-infrared.

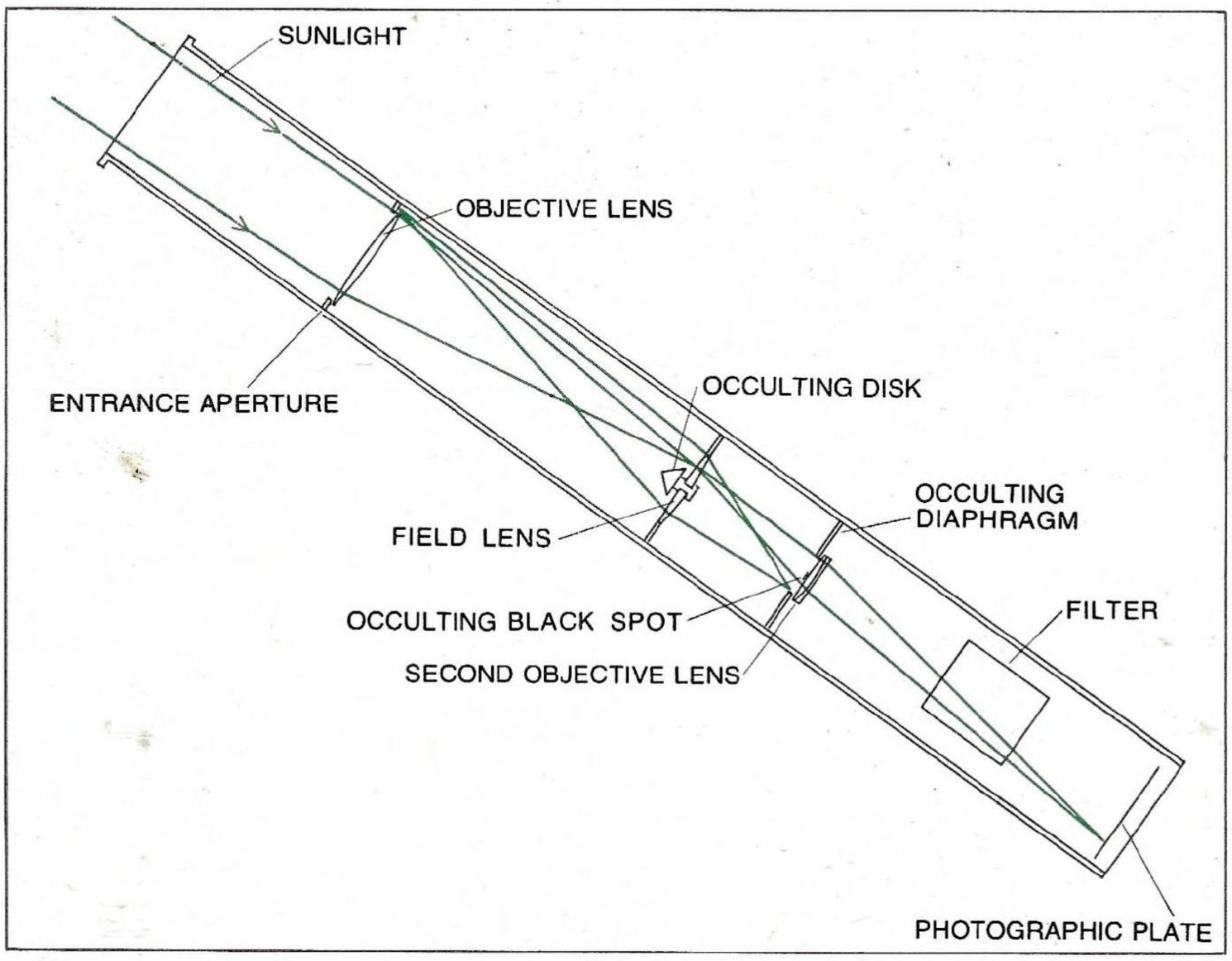
In order to release many electrons from their atomic bonds the gas must be very hot indeed. The emission lines also indicate the electron temperature of the corona in another way. They are much broader than the absorption lines from the photosphere, which are formed at an average temperature of a mere 6,000 de-



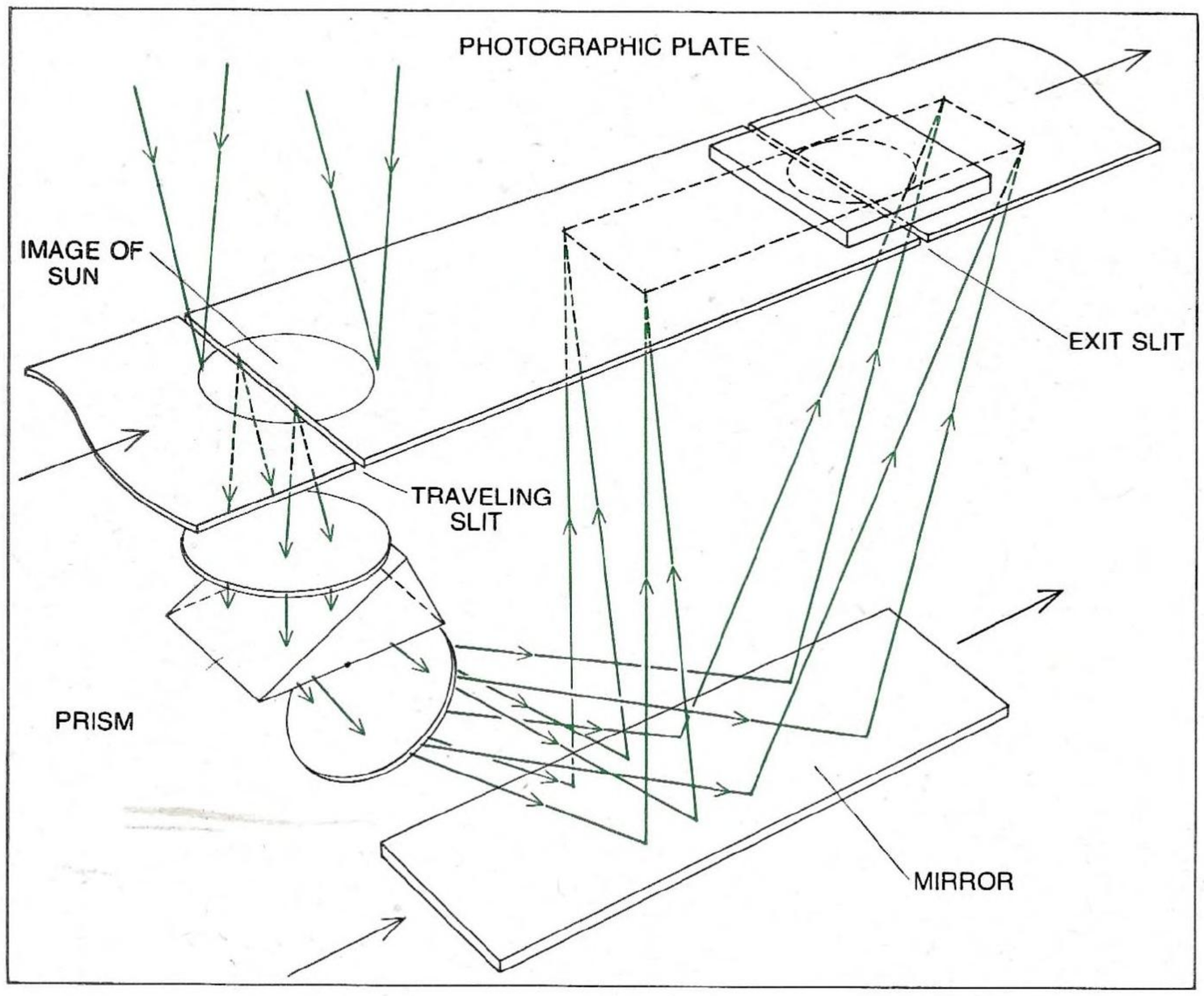
ENTIRE CORONA was photographed during the total eclipse of June 30 from Loiyengalan in Kenya by John W. Firor, Joseph H. Rush, Carl G. Lilliequist, Leon B. Lacey and Howar K. Hull of the High Altitude Observatory of Boulder, Colo. The photograph was taken i red light at a wavelength of 6,500 angstroms through a neutral-density filter whose densit decreased radially outward from its center. Such a filter suppresses the bright inner coron in order to show the faint outer streamers in the same photograph. Intricate details of th corona are thus made visible. The circular halo near the ends of the streamers was caused b the filter's not evenly suppressing the light from the unusually bright sky during the eclips



INNER CORONA was photographed on March 8, 1970, the day after a total eclipse, with coronagraph at the Mees Solar Laboratory of the University of Hawaii on the rim o Haleakala Crater on Maui. The picture is actually a composite of six images printed to gether to reduce the "noise" in each individual image. Photograph was made in green ligh of "forbidden" emission line of 13-times-ionized iron at a wavelength of 5,303 angstroms



CORONAGRAPH allows the inner corona of the sun to be photographed and analyzed without an eclipse. Sunlight is focused on an occulting disk, which blocks out the bright photosphere. A diaphragm removes a bright ring of light diffracted by the periphery of the entrance aperture; a black spot at the center of the second objective lens eliminates the bright spot that forms in the center of the image from internal reflections within the main lens. A second objective lens focuses the image of the corona on a filter, which isolates the spectral region to be photographed. Light is coming from only one limb of sun and is thus off axis.



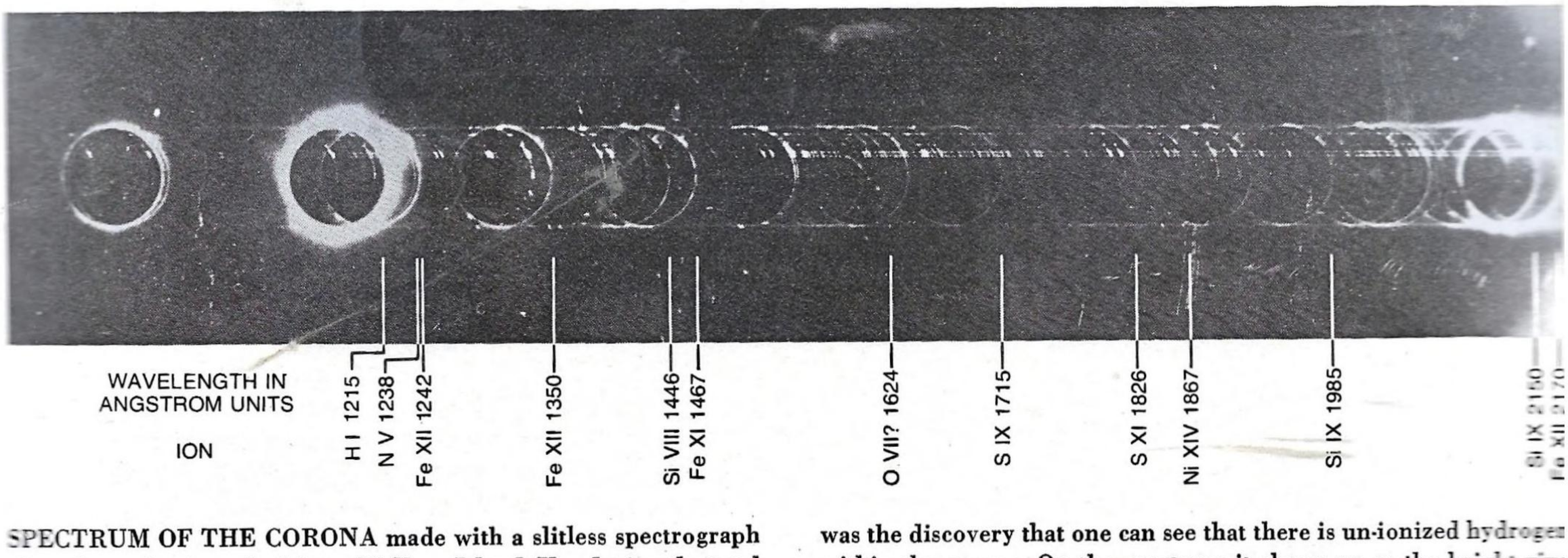
SPECTROHELIOGRAPH photographs the sun in one particular wavelength. Light from the sun enters a traveling slit and is dispersed into its spectrum of wavelengths by either a prism spectrograph (*as shown here*) or with a diffraction grating. One wavelength is isolated by a second slit. As the first slit scans the sun to build up an image, the second slit travels across the photographic plate with the same motion, so that the picture is built up in one narrow spectral region. In the case of spectroheliographs aboard the Orbiting Solar Observatory (OSO) satellites pictures such as the one on the cover of this issue of SCIENTIFIC AMERICAN are not directly photographed. Images are reconstructed from brightness measurements made photoelectrically, recorded on magnetic tape and telemetered to the ground.

grees. Here broader lines mean higher temperatures. All these lines are "forbidden" in ordinary conditions on the earth, meaning that the probability that radiation of those wavelengths will be emitted is very low. Solar forbidden lines result when the electron in an atom drops to a state of lower energy from a state of higher energy that is metastable, or long-lived. The density of the corona is so low that the atoms are not deexcited by collisions before they have a chance to radiate the energy.

Radio astronomy yields an independent picture of the corona. As the sun is examined at progressively longer wavelengths progressively higher layers come into view. Thus at centimeter wavelengths the radiation is emitted by the chromosphere, and at meter wavelengths it is emitted by the corona. Indeed, as the sun is scanned at longer and longer radio wavelengths the size of the image increases. Spatial structure in the corona is studied on a second-by-second basis by a radioheliograph composed of 96 linked antennas each 45 feet in diameter at Culgoora in Australia. The structure of the corona can also be studied by radar: by bouncing radio waves of different lengths off it. Such observations, together with theoretical calculations, are in agreement in showing that the corona has a temperature of two million degrees K. and has active regions of even higher temperature.

The earth's atmosphere does not pass electromagnetic waves that are shorter than about 3,000 angstroms, which is in the ultraviolet region of the spectrum. Therefore instruments have been sent above the atmosphere to gather short-wavelength information about the corona. Richard Tousey of the Naval Research Laboratory, who has been making spectra of the sun for many years with apparatus carried aloft in rockets, was the pioneer. In the spectral region of the shortest ultraviolet wavelengths and X-ray wavelengths one can even see the basic "permitted" spectral lines of the corona and not just the forbidden lines.

More recently satellites in orbit around the earth have provided stable platforms for observing ultraviolet radiation from the chromosphere and the corona. Leo Goldberg, who was then at the Harvard College Observatory, headed a group that flew an instrument that could function either as a spectrograph or as a spectroheliograph on two of the Orbiting Solar Observatories launched by the National Aeronautics and Space Administration: OSO-IV and OSO-VI. In the spectrograph mode the



SPECTRUM OF THE CORONA made with a slitless spectrograph aboard a rocket launched from Wallops Island, Va., during the total solar eclipse of March 7, 1970, showed 25 previously unknown spectral lines in the extreme ultraviolet. Thirteen of them are shown in this photograph. The spectrograph was not equipped with a slit because the image of the corona or chromosphere is so narrow that it acts as its own slit. Spectral lines from the chromosphere are short arcs, since they come from one limb of the sun at a time. Coronal lines are emitted higher above the sun's surface and show as complete circles. One particularly surprising result of this rocket flight was the discovery that one can see that there is un-ionized hydroge within the corona. On the spectrum it shows up as the bright rin labeled *H* I. The experiment was a joint venture of the Harvar College Observatory, the Imperial College of Science and Technol ogy, York University and the British Science Research Council' Astrophysics Research Unit at Culham Laboratory. Un-ionized spe cies of an element is labeled with Roman numeral I, the first ion ized state by II, and so on. *H* is hydrogen, *N* is nitrogen, *Fe* is iron *Si* is silicon, *O* is oxygen, *S* is sulfur and *Ni* is nickel. Number afte each species is the wavelength of the spectral line in angstroms

instrument scanned the spectrum of the sun in the far-ultraviolet. The solar image was held steady while the angle of a diffraction grating was changed. The grating dispersed the radiation from the sun into its various wavelengths. In this way the different wavelengths of the spectrum could be made to fall in turn on a photomultiplier tube, which thus was able to record the intensity of the sun's radiation at each wavelength. In the spectroheliograph mode the instrument worked the opposite way. The spectroheliograms were made by holding the diffraction grating at one angle, so that only a single wavelength fell on the photomultiplier. The solar image was then scanned in a raster pattern to build up a picture of the sun in that one wavelength.

The resolution of the equipment on OSO-IV was one minute of arc. The resolution was improved to half a minute of arc on OSO-VI. Although that resolution does not match the resolution of one second of arc that can sometimes be achieved by instruments on the ground, much important information has been gained from the study of the far-ultraviolet region of the sun's spectrum from above the earth's atmosphere.

Each region of a particular temperature and density in the corona is characterized by emission from a particular ion. A sequence of spectroheliograms made at wavelengths corresponding to increasingly higher ionized states shows that greater heights within the corona are revealed at higher degrees of ionization. Thus it is possible to build up a three-dimensional model of the corona's structure.

An unusual and successful experiment was carried aloft in a rocket during the eclipse of March, 1970. It was prepared jointly by the Harvard College Observatory, the Imperial College of Science and Technology, York University and the British Science Research Council's Astrophysics Research Unit at Culham Laboratory. That group obtained spectra of the corona and of the chromosphere in the ultraviolet region from 977 to 2,200 angstroms and discovered 25 new coronal lines. Since that region of the spectrum is closed to observers on the ground, many of the spectral lines had not been analyzed. This line of coronal investigation is in its infancy.

One additional result of the March 1970 rocket flight was the surprising discovery that un-ionized hydrogen is visible within the corona. It was detected in the radiation of the ultraviolet spectral line designated Lyman alpha, which is emitted by a hydrogen atom when an electron drops to the ground state from the next higher energy level. The temperature of the corona is so extremely high that almost all of its hydrogen must be ionized. Nevertheless, the minute fraction that remains un-ionized—perhaps one atom in 10 million—can scatter enough radiation to be detected.

Another area of recent investigation has been the study of the sun at X-ray wavelengths between one and 100 angstroms, most notably from rockets and satellites by a group under Riccardo Giacconi at American Science and En gineering in Cambridge, Mass. Becaus X rays are too energetic and penetratin to be focused by ordinary telescop optics, Giacconi and his group have de signed optics in which the rays are re flected at flat, grazing angles. With suc apparatus they have succeeded in re solving detail to one second of arc. rays are emitted mainly from "hot spots in the corona high above active region on the surface of the sun. In these ho spots a temperature of four million de grees K. is not uncommon, althoug some of the radiation is not simple the mal radiation and may reflect interac tions of charged particles with the coro na's magnetic field.

Like the evidence from the visible light and radio regions of the spectrum information from the ultraviolet an X-ray regions clearly indicates that th temperature of the corona is in the mi lions of degrees. It must be remembered however, that this temperature does no imply that there is a great amount energy present. The corona is very ten uous. There are only some 10^9 electron per cubic centimeter at its base, and th number decreases rapidly with heigh That density is 10 million times less tha the electron density in the photospher Although each individual electron moving at a high velocity and thus has high kinetic energy, the fact that the are so few electrons means that the tot energy of the corona is quite low.

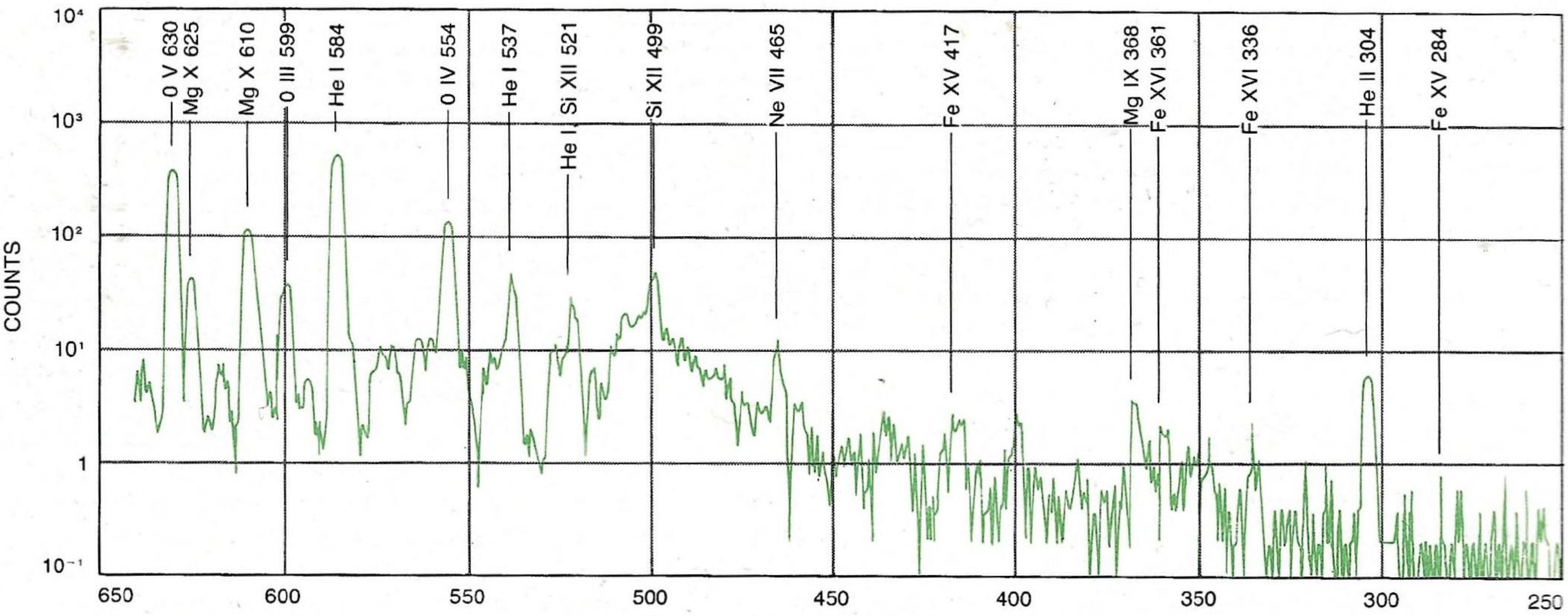
Nonetheless, the question is: Whe do the individual electrons get their hig kinetic energy? The energy wells up int

the corona as shock waves from lower levels of the sun, probably from below the photosphere in the convective zone [*see illustration on page 70*]. The temperature rises throughout the chromosphere and then jumps rapidly a million degrees in the few thousand kilometers immediately above the chromosphere. The exact mechanism by which the energy is transported to the corona and then dissipated is a matter of intensive research and some controversy.

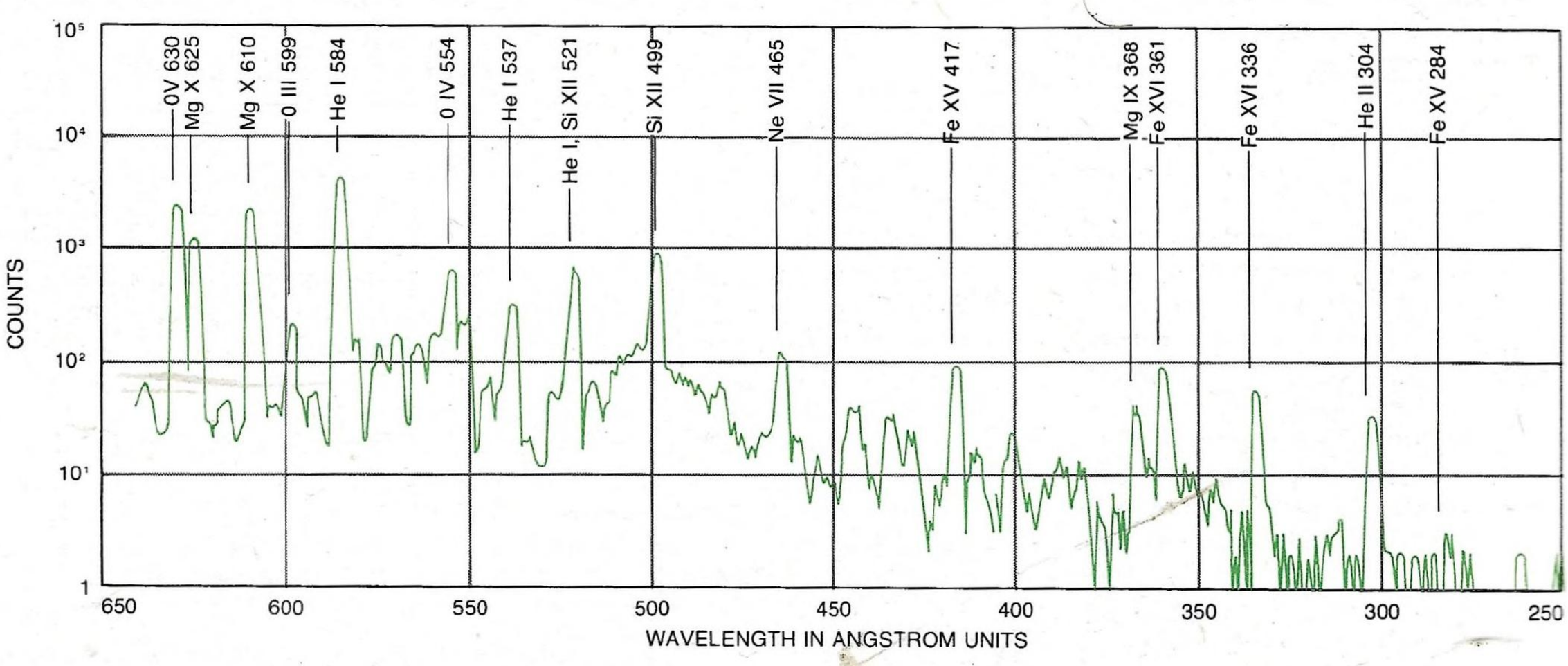
The emission lines from the highly ionized atoms make it possible to detect the corona even without a solar eclipse. Ground-based observations of these lines can be made from a few ideal sites. In principle the requirements for such observations are simple: the observer must have a very clean sky and very clean optics. In practice, however, these requirements are difficult to meet, and it was a major achievement when Bernard Lyot of France succeeded in constructing a coronagraph in the 1930's.

A coronagraph is usually a refracting telescope because microscopic pits in the mirrors of a reflecting telescope scatter too much light. At the focus of the primary lens of the telescope an image of the sun is formed on a small occulting disk that is exactly the size of the image of the photosphere. With the intense photospheric light blocked, there is hope of detecting the corona. The image of the corona is refocused and sent through filters that select the desired wavelengths for observation. Observations are usually made through filters that isolate the wavelengths around a coronal emission line, since such lines are brighter than the continuous spectrum.

Making a successful coronagraph is still something of an art. That fact is captured in an article on coronagraphs written by John W. Evans, director of the Sacramento Peak Observatory in Sunspot, N.M., in which he describes



SPECTRUM OF CORONA OVER QUIET REGION of the sun from 650 to 250 angstroms was measured from the Harvard College Observatory spectrometer aboard OSO-VI. From 504 to 470 angstroms the continuous spectrum of helium is visible as a gradual rise in intensity. *Mg* is magnesium, *He* is helium and *Ne* is neon. The principal investigators were Andrea K. Dupree, Martin C. E. Huber, Robert W. Noyes, William H. Parkinson, Edmond M. Reeves and George L. Withbroe of Harvard College Observatory.

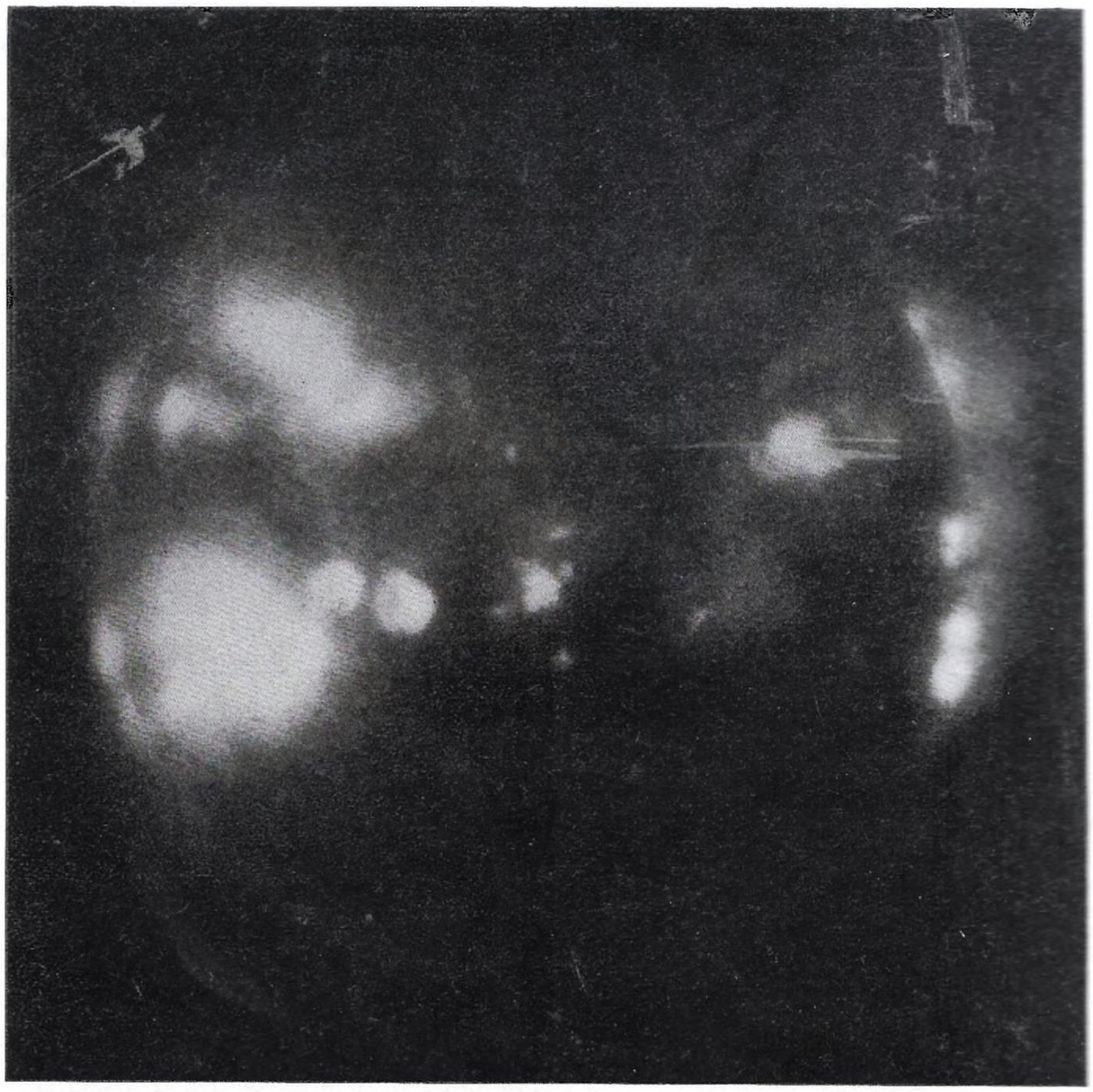


SPECTRUM OF CORONA OVER ACTIVE REGION of the sun was measured from the Harvard spectrometer on OSO-VI in an area of sunspots and flares. The entire spectrum is about 10 times stronger than the quiet-region one at top. Also certain spectral lines, such as the line of nine-times-ionized magnesium at 625 angstroms, are enhanced with respect to the background continuous spectrum.

how to coat the primary lens with an almost infinitesimal amount of oil in order to minimize scattered light: "Touch the side of the nose with a forefinger and lightly touch the surface of the lens in two or three spots, leaving distinct finger marks. Now . . . spread the oil."

Sites suitable for coronagraph observations are rare. They must be on a high mountain above much of the earth's atmosphere and the sky must be exceptionally free of dust. One of the main sites in the U.S. is the Sacramento Peak Observatory, which is at an altitude of 2,811 meters (9,200 feet).

The Hawaiian Islands have become prime sites for coronagraphs because general meteorological conditions keep atmospheric dust below the high mountains. The University of Hawaii has developed an exceptional site at an altitude of 3,054 meters (10,000 feet) on the rim of Haleakala Crater on the island of Maui. There John T. Jefferies, Jack B. Zirker and Frank Q. Orrall form an active group of coronal investigators. The skies are so clean that the scattering of light by the atmosphere near the disk of the sun is commonly less than 10 millionths of the total intensity of the sun [*see illustration on next page*]. Observations of the corona can be carried out perhaps 275 days of the year. The High Altitude Observatory of Boulder, Colo., also has a coronal site in Hawaii, on the mountain of Mauna Loa on the main island. Other major coronagraph sites around the world are at Arosa in Switzerland, the Pic du Midi in France, Kislovodsk in the U.S.S.R. and Norikura in Japan.



X-RAY PICTURE OF CORONA was made from a rocket launched by American Science and Engineering on the day of the March 7, 1970, total solar eclipse. (Rocket was outside the path of totality.) Wavelengths photographed ranged from three to 30 angstroms and from 44 to 55 angstroms. X-ray features corresponded to coronal features seen in white light.

When there is no eclipse, the *K* corona can be detected only with great difficulty. The electrons of the *K* corona polarize the photospheric light as they scatter it. Polarimeters have been built and used in connection with coronagraphs to observe the *K* corona. Such observations can yield information about the changes in the inner corona from one day to the next.

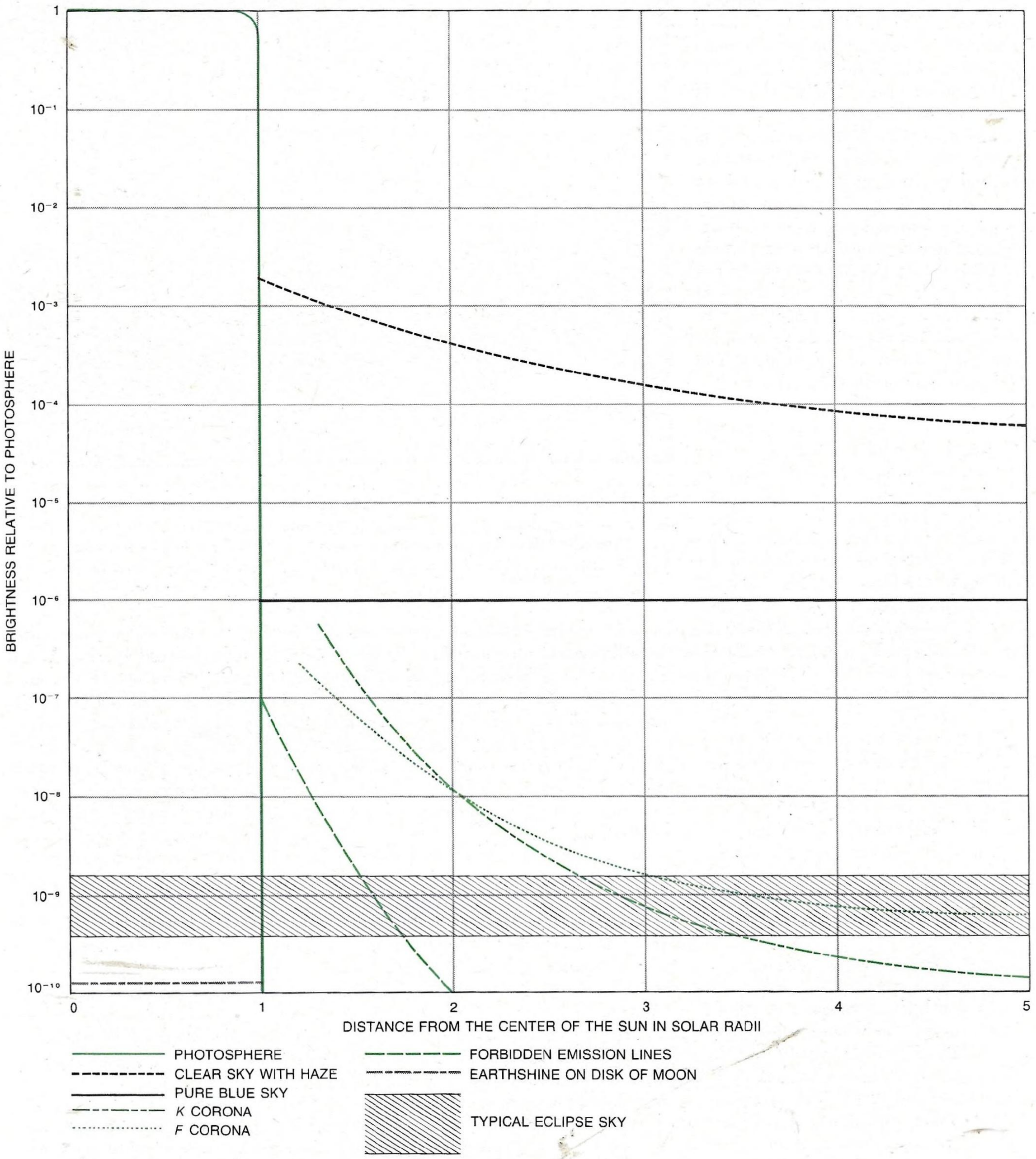
Certain forbidden spectral lines from highly ionized atoms have recently been detected at infrared wavelengths longer than those that can be observed from the ground. During the solar eclipse of November 12, 1966, Guido Munch, Gerry Neugebauer and Dan McCammon of the Hale Observatories detected two new lines. During the eclipse of March, 1970, Kenneth H. Olsen, Charles R. Anderson and John N. Stewart of the Los Alamos Scientific Laboratory detected nine more lines, all in the range of wavelengths from 10,000 to 30,000 angstroms. All these lines were observed from aircraft that flew above much of the earth's atmospheric water vapor, which absorbs the infrared wavelengths. Jet aircraft can also prolong eclipses by chasing the moon's shadow; the supersonic *Concorde* prolonged the totality of the June 30 eclipse to an unprecedented 74 minutes.

The relationship of the corona's density and structure to its magnetic field can be studied both theoretically and observationally. Gordon Newkirk, Jr., and Martin D. Altschuler of the High Altitude Observatory have developed a method and a computer program for deriving the magnetic fields in space from magnetic regions observed on the surface of the sun. Their results can be displayed as diagrams of magnetic lines of force extending into space above the solar surface. The coronal structures presumably follow the magnetic lines of force.

Kenneth Schatten and Norman F. Ness of the Goddard Space Flight Center of NASA and John M. Wilcox of the University of California at Berkeley have devised an alternative method of predicting the structure of the corona. In order to make the calculations more realistic they assume that the source of the interplanetary magnetic field is an imaginary surface six-tenths of a solar radius above the photosphere. The magnetic field extends radially out from the surface and behaves according to certain simplified rules. Before the eclipses of September 22, 1968, and March, 1970, Schatten made predictions of what the coronal structure would be like. They seemed to agree reasonably well with the actual structure that eventually appeared. Gerald W. Pneuman and Roger A. Kopp of the High Altitude Observatory have developed a fuller theoretical treatment.

The solar telescopes that are now flying in space are revolutionizing observations of the corona. OSO-VII, launched in September, 1971, carried a coronagraph into orbit with an occulting disk at the end of a long boom. Coronagraphs orbited in space can be con-

structed differently from their ground-based counterparts and can reach much lower levels of intensity. The Apollo Telescope Mount of Skylab, the manned satellite observatory now in orbit, also carries a coronagraph. The Apollo Telescope Mount has television screens that display the detailed structure of the surface of the sun in the light of the hydrogen-alpha line and at X-ray wavelengths, and of the corona in white light. The major experiments of Skylab include a spectroheliometer from the Harvard College Observatory that is mapping the sun at wavelengths of from 300 to 1,350 angstroms with a resolution of five seconds of arc, a visible-light coronagraph from the High Altitude Observatory that provides pictures showing the structure of the corona between 1.5 and six solar radii at regular intervals, ultraviolet spectrographs from the Naval Research Laboratory and X-ray telescopes from American Science and Engineering and



RELATIVE INTENSITIES of the corona, of other parts of the sun and of the sky are shown with respect to the brilliant photosphere. The diagram is based on one made by H. C. van de Hulst. It is evident why the corona cannot be seen in the ordinary daylight sky and yet appears so clearly during a total eclipse of the sun. Curve for forbidden lines reflects total intensity of all such lines in the sun.

from the George C. Marshall Space Flight Center of NASA and the Aerospace Corporation.

Now that there is information about the corona flowing in daily from OSO-VII and Skylab, observations can be compared with theory much more frequently than they could if we had to rely exclusively on eclipses. It will be many years before we solar physicists will have synthesized the vast quantities of data we are now receiving from space. Nonetheless, we can be reasonably certain that current models of the corona will have to be drastically revised.

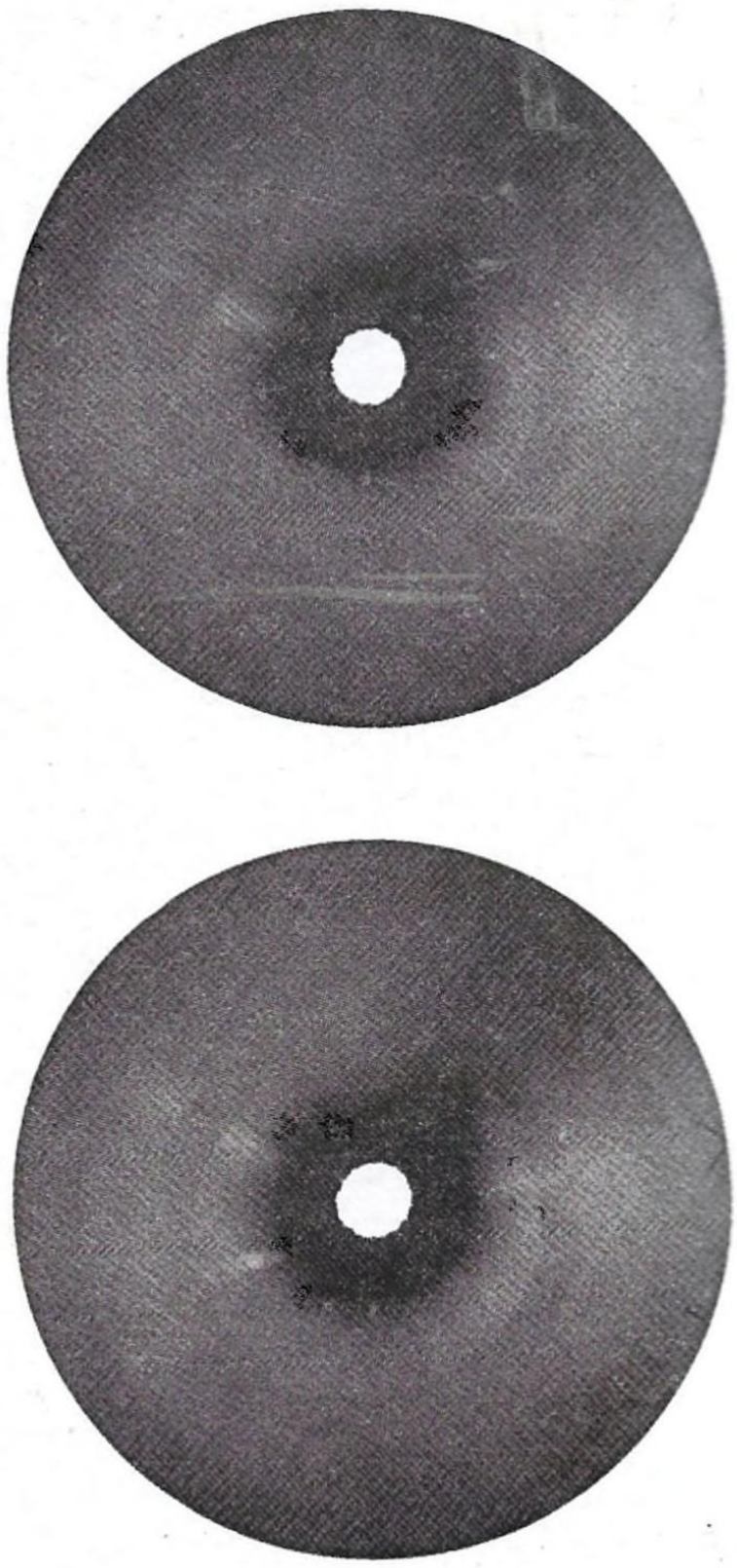
Observations of the corona always show a total intensity that includes not only a contribution from the *K* corona but also one from the *F* corona. How much the *F* corona contributes can be determined, because it differs from the *K* corona in two ways: in its spectra and in the polarization of its light. Donald H. Menzel and I have carried out a series of spectrographic and polarization observations during the past four total solar eclipses to investigate the separation of the *K* corona from the *F* corona. Whereas light scattered by electrons in the *K* corona is highly polarized, light scattered by the cold interplanetary dust of the *F* corona is basically unpolarized. The degree of polarization of the corona as a whole reaches a maximum of about 40 percent at a distance of 1.5 solar radii out from the center of the solar disk. Thereafter the amount of polarization decreases. That decrease can be interpreted as being the result of the superposition of the unpolarized *F* corona on the polarized *K* corona. The *K* corona itself reaches a polarization level of about 60 percent at about three solar radii.

In order to separate the polarized component from the unpolarized component, one must record the intensity of the corona during an eclipse through polarizers set at different angles. The method has a fundamental limitation, however, that has been pointed out by D. E. Blackwell of the University of Oxford. This is that the light of the *F* corona is not totally unpolarized; it has a residual polarization of a few percent. Thus results obtained for the separation of the *F* corona and the *K* corona beyond about five solar radii, where the total polarization is less than 10 percent, are inaccurate.

In order to separate the two components accurately one must examine the spectrum of the corona. As I have mentioned, the *F* corona simply scatters the Fraunhofer absorption lines from the solar photosphere. It does not affect the amount they absorb from the background level of the continuous spectrum. In the *K* corona, however, all the lines are washed out. To separate the two coronal components one must measure the intensity of the absorption lines in a spectrum made during an eclipse and compare those measurements with measurements of the lines in a spectrum of the photosphere made at another time with the same instrument. The degree to which the intensity of the spectral lines is reduced reflects the contribution of the *K* corona.

This method has been used for the hydrogen-alpha line, particularly by Blackwell and A. D. Petford. They derived a model for the two components of the corona that includes the distribution of temperature and the density of electrons near the sun out to a distance of 16 solar radii. Many of their observations were carried out from an aircraft at an altitude of 30,000 feet during the eclipse of July, 1963. The technique is a refinement of Blackwell's earlier work during the eclipse of June, 1954. During that first experiment he flew in an open cockpit at 30,000 feet. He stoically remarked that physiological difficulties made it inadvisable to attempt observations from a greater height, even though the aircraft could have climbed 13,000 feet higher.

One reason there is such interest in the outer corona is that there is a large gap between the corona we can detect during eclipses and the faint glow at the horizon known as the zodiacal light. The zodiacal light is visible at dark locations before sunrise and after sunset. It can be



JETLIKE STREAMER formed quickly in the southeastern corona and disappeared rapidly within a period of less than five hours. It was photographed from a visible-light coronagraph aboard OSO-VII in four successive orbits on May 9, 1973. The top frame shows the sun at 5 hours 43 minutes Greenwich Mean Time, before the streamer appeared; the next frame shows the beginning of the streamer at 7 hours 15 minutes; the third frame shows the streamer nearly dissipated at 8 hours 47 minutes; the bottom frame shows the sun at 10 hours 17 minutes, after the streamer had disappeared. The time scale of the entire event is much shorter than was previously thought to be the case. The photographs were supplied by the Rocket Spectroscopy Branch of the Naval Research Laboratory in Washington, D.C.

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detected out to about 80 solar radii. Presumably it is merely an extension of the *F* corona.

One set of data that helps to bridge the gap comes from the unmanned lunar vehicles of the Surveyor series. On the moon's airless surface there is obviously no atmospheric scattering of light. The corona simply rises each morning before the sun's disk and sets each evening after it. J. David Bohlin of the Naval Research Laboratory analyzed some of the data from *Surveyor 6* and *Surveyor 7*. He could follow one coronal streamer detected by *Surveyor 7* out to 22 solar radii.

Measurements at radio wavelengths can also be utilized to find the density of electrons in the outer corona. The corona tends to displace the apparent radio position of the Crab Nebula or quasars as they pass behind it. It also changes the apparent period of the radio signal from pulsars. Both types of change depend on the total density of electrons in the line of sight.

The structure of the corona varies strikingly from one eclipse to another. Its form has long been linked with the cycle of solar activity associated with the 11-year sunspot cycle. The shape of the corona is quite irregular when the number of sunspots is at a minimum (as

LOOPS OF IONIZED PARTICLES streaming away from the sun's surface more than 25,000 miles into space are shown in an electronically recorded image made by a scanning ultraviolet spectroheliometer aboard the manned satellite Skylab. The instrument is one of the solar physics experiments in the Apollo Telescope Mount and is the project of a group from the Harvard College Observatory led by Reeves. The Skylab spectroheliometer has a resolution some 30 times greater than that of similar instruments flown on the Orbiting Solar Observatories, revealing these distinct loops in the wavelength of 14-times-ionized iron at 417 angstroms. With the ultraviolet measurements very accurate temperatures can be determined for levels within the sun's atmosphere. Such measurements are made twice a day during both the manned and the unmanned periods of the Skylab mission.

it is now); it becomes much more symmetrical when the number is at a maximum. At sunspot minimum the strong solar activity is confined largely to the equatorial regions of the sun, and so at that time the corona mainly displays equatorial streamers. At sunspot maximum solar activity is much more general, and the corona extends farther in all directions.

The human eye sees the corona out to a few solar radii. Radial-density filters, which are now used at eclipses, show much detail. A radial-density filter is darker at the center than at the edges, and thus it allows the fainter outer corona to register within the limited dynamic range of film without overexposing the image of the brighter inner corona. Such photographs show with particular clarity that the spiky structure of the coronal streamers persists out to great distances from the sun.

These streamers attest to the fact that theoretical models of the corona's structure must have a number of components. Presumably a streamer is a region that has a slightly higher electron density than neighboring regions, so that it scatters more light. The newly discovered "holes" in the corona are regions of much lower density.

I believe the events of the current year will prove to have been extremely significant to our understanding of the corona. As the results from the June eclipse, from Skylab and from OSO-VII are fitted together, our ideas will change and our theories will improve. The picture that now seems to be emerging is that of a highly dynamic corona with large regions often changing within minutes or hours.

Calculations that have long been based on the assumption that the corona is a homogeneous, symmetrical cloud of gas must be thoroughly revised. We are now realizing that the complexity of the corona, and of the chromosphere as well, cannot be ignored if we want a model of the sun that is physically meaningful and not just a theoretical abstraction.

The lesson is an important one. The sun is only the nearest of billions of stars, concerning whose structure we are often content to accept general conceptions. Yet we know that other stars have chromospheres and coronas, and that many such stars are in a much more dynamic state than the sun is. The atmospheres of these stars must partake of the constant activity that now seems to characterize so much of the universe, which had long been regarded as being quite placid.

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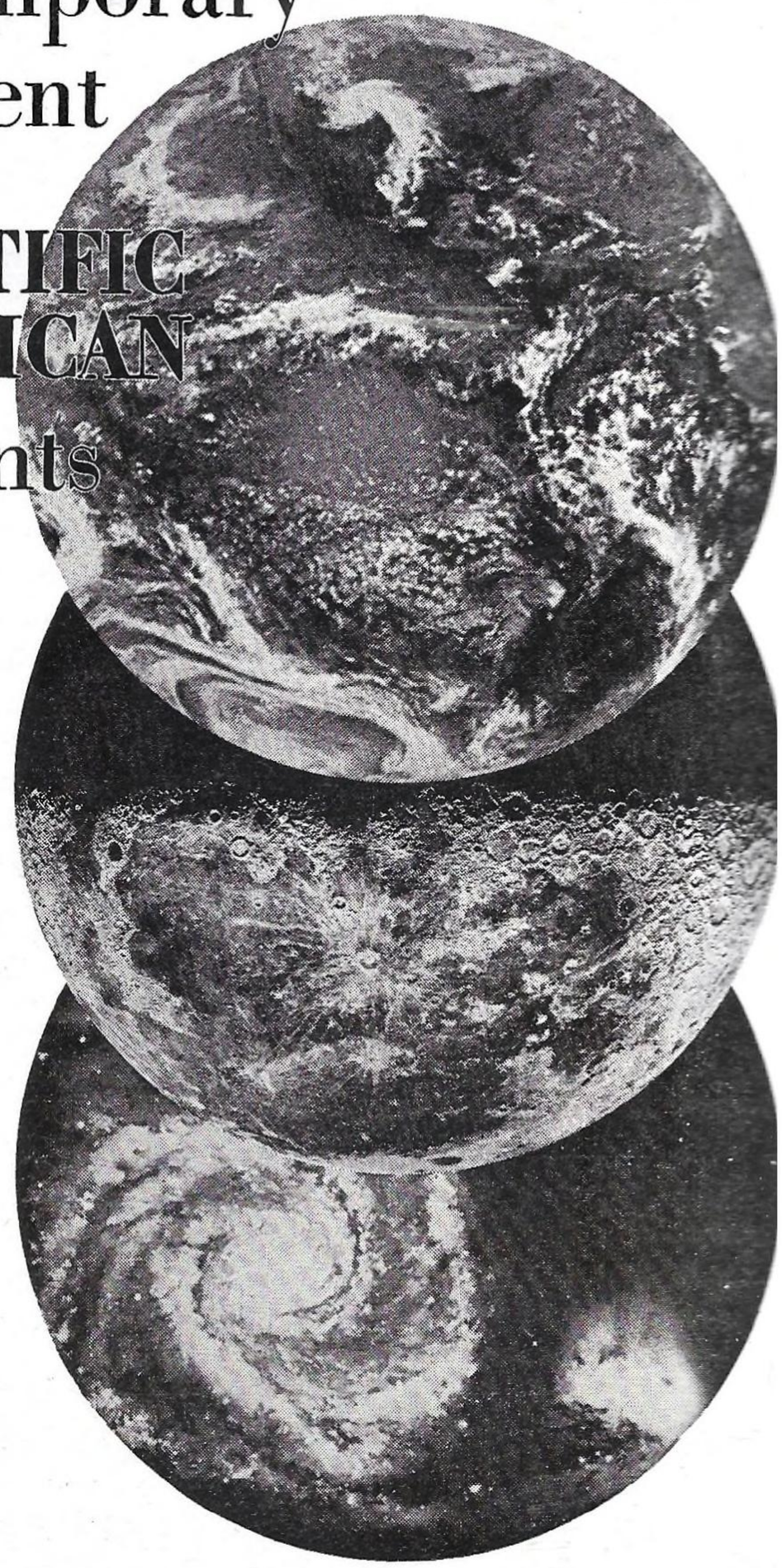

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stant to within a few percent in metal-to-metal contact, even if the load is increased by ten- to a hundredfold. Slide a steel ball over an acrylic plastic surface, though, and Leonardo's empirical approximation is found wanting: the "coefficient" is halved for a load increased sixteenfold. No more is friction proportional to load.

Why? Bowden put it crisply: "Putting two solids together is rather like turning Switzerland upside down and standing it on Austria—the area of intimate contact will be small." Those Alpine profiles are made visible nowadays in three dimensions by the scanning electron microscope, by viewing oblique sections with the optical microscope for vertical exaggeration or electronically by phonograph-pickup techniques. All these methods are exhibited here in photographs that complement the text.

The low-contact area is confirmed by electrical-resistivity measurements, allowing with some difficulty for the layers of oxide and adsorbed gases that dominate "clean" metal surfaces in the air ocean in which we engineering fishes must build. (At high loads the oxide films break down, the contact becomes a good conductor and the coefficient of friction can triple.) The load is borne on "the tips of the surface asperities," and the area of actual contact is tiny. The peaks deform permanently (they feel a high load pressure, of course) until the load is carried by a contact area big enough to support it. That value depends on the material; for mild steel it is some 10 tons per square centimeter.

Slide a heavy toolbox across a steel plate and the load is in fact supported by a contact area of deformed steel no bigger than a comma printed on this page. That area will adjust its size, independent of the size of the bodies, and stay pretty closely proportional to the load; the shape and the number of the contact peaks make little difference. For plastic materials the area adjustments are in fact viscous flows and hence time-dependent; the coefficient therefore varies with speed as well as load.

Friction force between clean metal surfaces is then mainly the force required to shear the friction junctions that form by the cold-welding of heavily loaded peaks. That shear force obeys the old laws of Leonardo, and it is plainly sensitive to grease films and to surface changes that affect the nature of the junctions. The transfer of metal, even under small load and slow motions at room temperature, rather hard to accept at first, is demonstrated by direct autoradiographs. A slider of radioactive lead leaves tiny fragments behind, and these can photograph themselves if an emulsion is left in contact with the track of the slider.

Wear always accompanies friction. Every junction must be sheared, but not every shear transfers material; the junction can fail either at a weld proper or at an oxide-layer film between metal surfaces. For steel on steel perhaps 1 percent of the junctions produce a wear fragment; for polyethylene on steel the "welds" are weak, and only one in 10 million transfers material.

There is a puzzle still. Why do materials not adhere at their friction junctions whenever we put one down on another? The answer is twofold: carry out the experiment with clean, soft metals, such as lead, and they do adhere; this was first described in 1734. At high temperatures the effect is even stronger: metal powders sinter together under pressure. Note, however, that adhesion can only be measured by relaxing the load. The big valleys around the little contact summits are stressed only lightly by the load; they will elastically return to their original forms, to change the shape of the interface and "snap [the weak junctions] apart one by one so that by the time we are ready to measure the adhesion there are practically no junctions left." (The "wringing" of precision gage blocks together, which makes them adhere quite strongly, exploits the adhesion of the grease film present; degreased blocks "wrung" will really adhere, and the expensive steel surfaces will be ruined.)

Bearing metals, ski surfaces, lubricants and their additives, brakes and tires and more topics still are treated in this easily read although imperfectly organized book. Rolling friction turns out to arise from the internal losses that accompany elastic deformation of the surfaces. It is small, and lubrication helps it very little, because few junctions are made and those are merely peeled apart, a process much easier than shearing. Noble metals, such as gold, show a friction coefficient several times higher than metals that form oxide junctions; in a good vacuum heat-cleaned metal surfaces will weld readily. Starting at the contact peaks, the junction grows as the peaks flow and deform; the whole of the surface may become an enormous friction junction. The friction bears little relation to the load; the coefficient may reach 50 or more; the surface is heavily damaged.

In the purity of the vacuum the contact surface is simple, but the laws of friction are more complex. The book is a narrative of the sophistication that commonplace experience today demands of the physicist, and of a victory he has won, which would surely have delighted Leonardo.

NEUROPHARMACOLOGY AND BEHAVIOR, by V. G. Longo. W. H. Freeman and Company ($6.95). HALLUCINOGENS AND SHAMANISM, edited by Michael J. Harner. Oxford University Press ($8.50). THE BOTANY AND CHEMISTRY OF HALLUCINOGENS, by Richard Evans Schultes and Albert Hofmann. With a foreword by Heinrich Klüver. Charles C Thomas, Publisher ($14.75). Strange voyages, real and imaginary, are the substance of these three diverse but interrelated volumes: Longo, a brief clinical text; Harner, an anthropological symposium; Schultes and Hofmann, organized around plant families.

In 1943 Albert Hofmann rode his bicycle home at lunchtime from the Basel laboratory where he had been preparing derivatives of lysergic acid. The familiar short trip seemed endless, complex, frightening. War "classified" his results for several years. Michael Harner, a New School anthropologist, in 1961 drank in the field a tea made from the boiled bark of a liana that grows in the upper Amazon; under the influence of its alkaloids, harmine and dimethyltryptamine (DMT) among others, he "met bird-headed people [and] enlisted the services of other spirit helpers . . . to fly through the far reaches of the Galaxy." Richard Schultes, economic botanist at Harvard, spent 13 happy years along the Amazon, collecting 24,000 plants, several languages and the habit of daily chewing coca. The psychologist Klüver, whose little 1928 book on mescal explicitly recruited the premedical student Schultes to his later career, sought out all over the U.S. people who had reported eidetic imagery, or "photographic" memory. By chance the noneidetic Klüver read that peyote might help him toward a share of the imagery; he first consumed mescal buttons in the laboratory at the University of Minnesota. Only Longo, a research pharmacologist with an atlas of electroencephalograph records to his credit, has stayed at home (in Rome) to prepare his book. (Although his book is succinct, it treats antipsychotics and tranquilizers as fully as hallucinogens.)

The fact is that among many hundreds of thousands of plant species a few hundred are important to human nutrition, and some 75 yield substances

Scientists in Search of Their Conscience

Edited by
Anthony R. Michaelis
and
Hugh Harvey

In June 1971 scientists from many countries met in Brussels to attend a symposium on *The Impact of Science on Society*. Their lectures and discussions at this meeting, organized by the European Committee of the Weizmann Institute of Science in Rehovot, Israel, are now available in this collective volume.

The responsibility of scientists for society's use of scientific findings was explored in depth at the Conference. Though no hard-and-fast conclusions were reached, the discussions clearly demonstrate that scientists are becoming aware that they can no longer claim that the pursuit of knowledge is divorced from its use. Yet, to face the responsibility for the application of their work would impair their freedom. The loss of freedom is part of the dilemma of science.

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The international colloquium organized by UNESCO on the tenth anniversary of the deaths within a week of one another—of both **Albert Einstein** and **Teilhard de Chardin,** brought together eminent scholars in a free discussion of the need to effect a synthesis, both of scientific knowledge and of the scientific and philosophical approaches to knowledge.

Contributors:

René Maheu • Ferdinand Gonseth • J. Robert Oppenheimer • Werner Heisenberg • Reverend Dominique Dubarle • Sir Julian Huxley • Giorgio de Santillana • Gerald Holton • B. M. Kedrov • François Le Lionnais • Louis de Broglie • René Poirier • Pierre Auger • Jean Piveteau • Reverend Pierre Leroy

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whose effect is narcotic or hallucinogenic. Among plants used by man for purposes other than food, the opium poppy, the tobacco plant, coca and certain large-flowering tree daturas of the northern Andes are species known only as cultivated plants.

There is clear evidence that religion too lies along this path: the psilocybin of the little Mexican mushrooms is associated with an antique cult of the highland Maya, whose stone icons of the mushroom have been found in widespread Guatemalan digs. One paper associates it with "tender, generous, brotherly feelings." These effects are not particularly noted in laboratory studies, one author dryly remarks. The ecstatic chant of the shaman of northeastern Oaxaca is today inspired by the same psilocybin: "the psychoanalyst listens, whereas the shaman speaks," wrote Claude Lévi-Strauss. Eloquence heals; there, in absolute darkness, is poetic ritual: "Thirteen white lights, says. Thirteen mountains of points, says."

Almost 20 years after LSD, Hofmann tested by self-experiment another alkaloid: d-lysergic acid amide. Structurally close to his old drug, this one was less active by a factor of 50 to 100. It was no novel product of the Sandoz synthesists, however, nor was it derived in any way from ergot fungi. It was there in the seeds of certain Mexican morning glories, seeds described by the early Spanish chroniclers as "held in great veneration," the source of a magic Aztec potion, ololiuqui, used to "communicate with the gods and receive the secret things."

The chief grocery-store hallucinogen is an alkaloid in the spice nutmeg. There is a little evidence for its use in India, both ancient and modern, and it is commonly taken in American prisons. Distortion of time and space, floating and flying sensations, separation of the limbs from the body and occasionally imagery can result from ingestion of a teaspoonful or two of the spice, usually with plenty of unpleasant side effects. Its active principle is uncertain, but the best theories suggest one constituent that the body metabolizes into a compound related to a strictly contemporary folk drug, called STP by its Haight-Ashbury discoverers about 10 years ago. (The name was taken from that of the proprietary oil additive, said to increase the pep and power of automobile engines.) It took a couple of years before Government investigators could buy samples of STP, isolate the drug and test it. It was the synthetic 2-5-methoxy-4-methylamphetamine. The structure of all these substances is broadly related to that of mescaline.

The use of plants in the Americas has always been remarkably varied; we know how much the fields of the Old World gained once the ocean was crossed. But Europe has its hallucinogens too. Harner and Longo (the latter's clinical-textbook style is at this point suddenly illumined with four engravings of witch flight from Goya) both discuss the role of "flying ointment" and various other potions in the ritual and personal experiences of European witches and warlocks. Harner's Jívaro shamans used both *Datura*, yielding scopolamine, like the European plants, and the non-European harmine alkaloids. But the *Datura* is "too strong," they held, for shamanism itself. A shaman must operate socially while under the influence; the *Datura* is apt for the vision quest, the search for supernatural contact, but it induces sleep and muddies the more complex side of ritual behavior. Therefore in Europe there were two distinct phases within the practice of witchcraft: the Esbat, a ritual meeting of adepts without drugs, and the Sabbat, the "orgiastic gathering," which was in fact somnolent and solitary, simply a flight trance under the influence of some *Datura*-rich ointment, with its scopolamine and hyoscyamine.

How does it all happen? We are far from understanding the basis of these remarkable pathologies. Longo's text notes the similarities or antagonisms of the drugs to known transmitter substances in the central nervous system, and considers as well the evidence of electrophysiology. Simple explanations—synchronizing certain systems of brain waves, resemblance to some natural transmitter compound—seem to promise well, but they peter out. The remarkable complex within our head is not yet mapped territory. The more credulous of the 10 anthropologists and fieldworkers who appear in the Harner collection are even tempted by a wondrous anecdote or two to believe that the vine snuff or the mushrooms connect the user with another world, or even with distant earthly lands.

The reader of these related books sees a much more comprehensive unity: the drugs disclose an interior world. Shaman or anthropologist, novelist or organic chemist, witch or neurophysiologist or volunteer, the richness is internal. Let the visual field part and glide, the images turn into color negatives, or bear stripes and edges, and we can see grand snakes and rare tigers, unknown black

priests or dragon-headed rulers; our experience fills our head with imaginative illusions. No vision has yet been recounted more powerful than that of August Kekulé's, who, while daydreaming without drugs on the London horse bus a century ago, saw serpents join head to tail to form the benzene ring.

GRAVITY'S RAINBOW, by Thomas Pynchon. The Viking Press ($15). A V-2 missile links the two ends of the ballistic parabola that is gravity's rainbow. At one end is London, dogged and ingenious; the other end is by extension Germany itself. This bulky, intimate, particular and detached novel, a work of the first magnitude, is a tale of V-2.

There is a protagonist at each root of the parabola: in London, Slothrop, the young New England intelligence lieutenant, with a hidden childhood under psychological experiment; on the Continent, a mad and perverse S.S. officer, Captain Weissmann, commander of a V-2 battery. Slothrop leaves London to spend the year in fugue across shattered nations, in a search for the unique rocket, serial number 00/000, that Weissmann once requisitioned and launched with the S-Gerät, strangest of all the payloads of the Wehrmacht. The prose is intricate, turbulent, streaming without rest in a spate of idea, event and allusion.

Here we merely note that this is a novel of a new sort. James Joyce grounded his flowing work on the ledges of epic, myth and folklore. *Gravity's Rainbow* instead founds its intricacies and expertise of allusion on science and technology, adjusted to the wartime *ambiance*. There are a number of remarkable set-piece essays, one on organic chemistry and its origins, one on operant conditioning, another on rocket dynamics. Ackeret and Leibniz, the Poisson distribution and double integrals are references as natural to Pynchon as limericks and vintages are to other novelists. To sketch one example, an apt connection is made between the serial wood engravings of late medieval German art, the calculus of Leibniz, the successive frames of an Ufa film and the unfolding time trajectory of the rocket, striking unheard a theater in London. Not all readers will persist up the wordstream past the bizarre and explicit sexual couplings, diverse as molecules, into the analytic heart of the novel; those who do will gain a richness of thought and motive, for which they must pay in spiritual coin. The literary reviewers have treated the novel as seriously as it deserves; it is a brilliant book, but be warned, that glow is icy cold.

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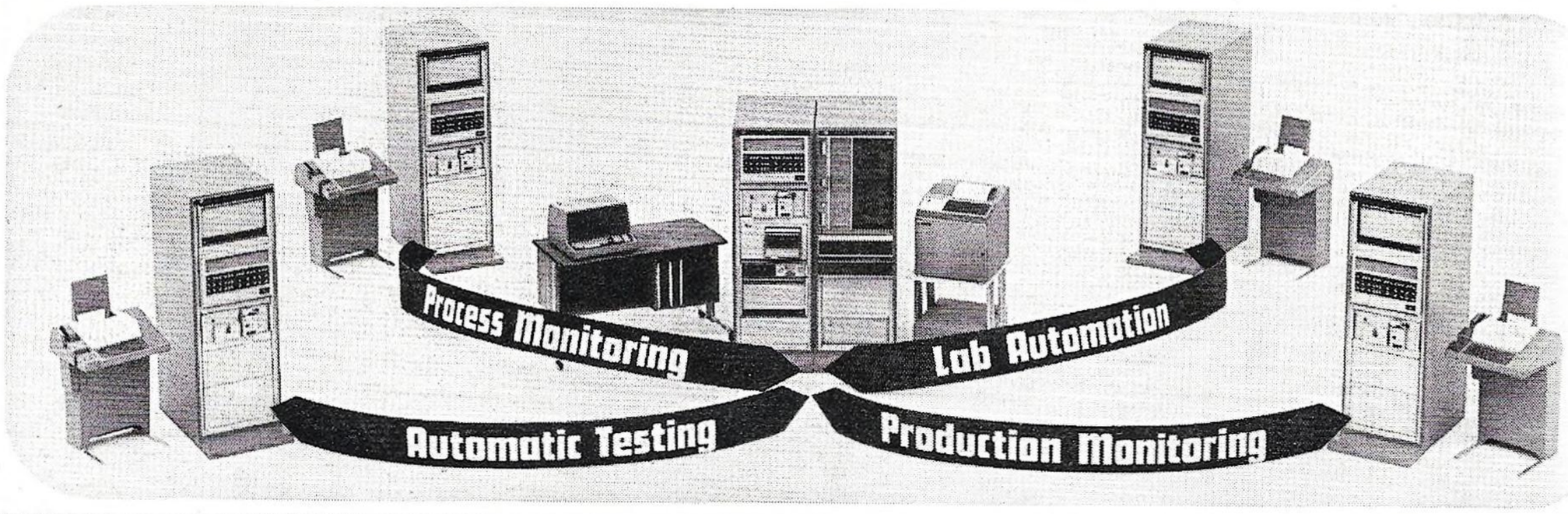
Key to it all are two Distributed Systems Packages: the HP 91701, about $6000 of hardware and software that establish and manage communications between the control 2100 and each satellite 2100 system; and the HP 91780 (about $5000) that performs a similar function for the central 2100 and host IBM computer.

If this idea interests you, ask for literature on Distributed Systems.



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An especially important application for ESCA appears to be in characterizing catalysts. Catalysts are essential to the manufacture of materials, yet determining the properties of these compounds and finding methods to evaluate their efficiency are important problems that until recently have defied almost all analytical techniques.

Predicting the performance of fresh catalysts has been equally difficult. ESCA offers hope here; not only can it determine the oxidation states of species at the surface, but it can give information about surface conductivity, an important parameter for characterizing catalyst activity.

Although early investigators have already made important discoveries in surface chemistry and physics with ESCA, they have been unable to realize its full potential because of the design limitations of the first generation of instruments.

In all these spectrometers, the raw X-rays

cludes that 23,000 barrels can be delivered every 24 hours, at 10 cents per barrel."

"The discovery of a human skeleton in one of the grottoes of Menton, a village on the south coast of France near Nice, has produced no small excitement in the scientific world. It appears from the recent investigations of M. Rivière that, at the upper portions of the caverns examined, remains of instruments and tools were found belonging to the prehistoric epoch that immediately preceded, in the west of Europe, the appearance of metals. While the fauna discovered in connection with the human relics indicate a very ancient paleontological epoch, the bone and stone instruments seem to point to a more recent period. The multiplicity of bone tools, needles, chisels and a *baton* of command, together with a peculiar necklace that closely resembles one found on the fossil man of Cro-Magnon, lead to the conclusion that the series of objects belongs to an age posterior to that of the bear, namely to that of the reindeer. It is believed, however, that the original owner of the skeleton existed during the latter age, and was buried in a cave formerly inhabited by men of the preceding epoch."

"The good news comes to us from Dundee, Scotland, of the safe arrival there of all the remaining survivors of the Hall arctic expedition, consisting of Captain Sidney O. Buddington and 12 others. The incidents and results of this latest polar exploration can be briefly summed up as follows: On the 29th of June, 1871, the steamer *Polaris*, Captain Charles F. Hall, sailed from New York on a voyage of arctic exploration. In August, 1871, she reached latitude 82°16′, the highest point ever attained by any vessel. Soon after the ship went into winter quarters Captain Hall was taken ill, and he died on November 8, 1871. Captain Buddington became master. In August, 1872, finding further progress northward impossible, Captain Buddington determined to return home, and the ship started for the south. She was now caught in the ice, and Captain Buddington caused a portion of the provisions and a part of the ship's company to be landed on the ice. On the night of October 15, the *Polaris* broke away from her icy moorings, leaving the hapless party of 19 persons on the ice. On the 30th of April, 1873, after 6½ months of dreary drifting, they were rescued and were safely landed at St. John's, Newfoundland."

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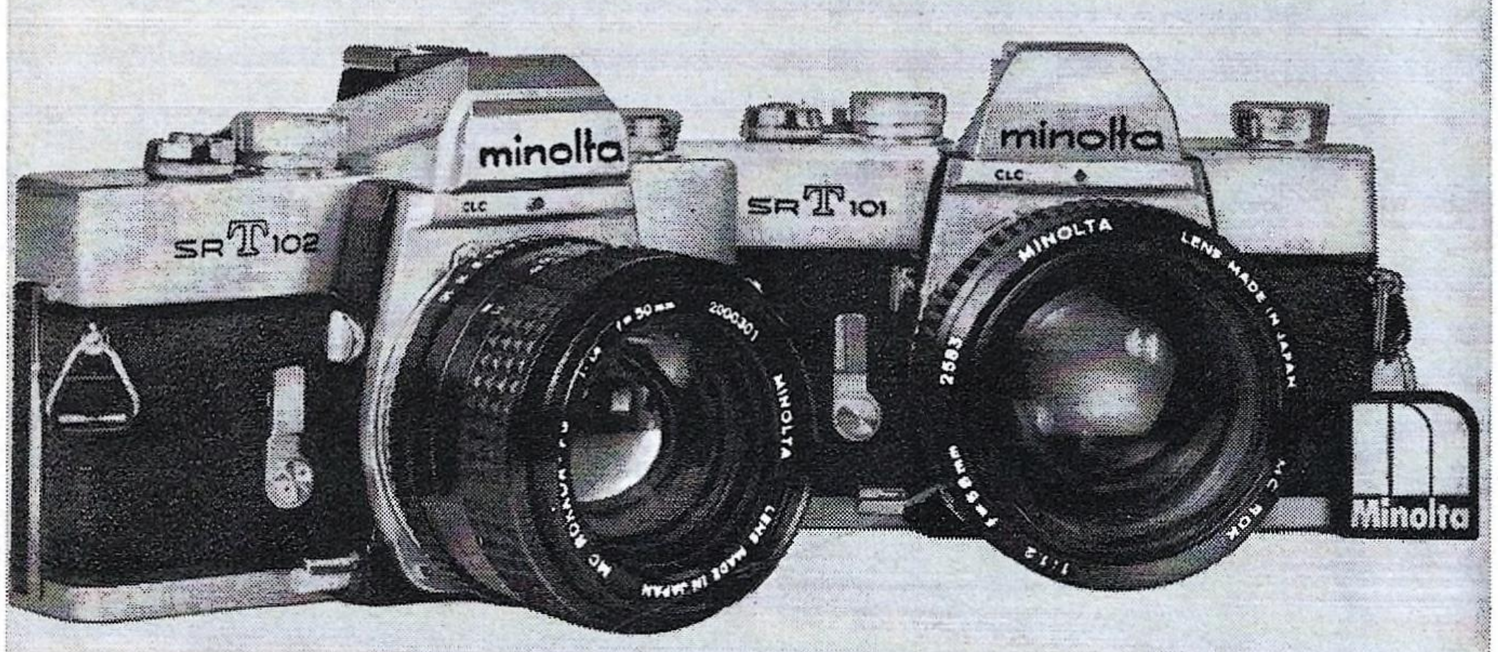

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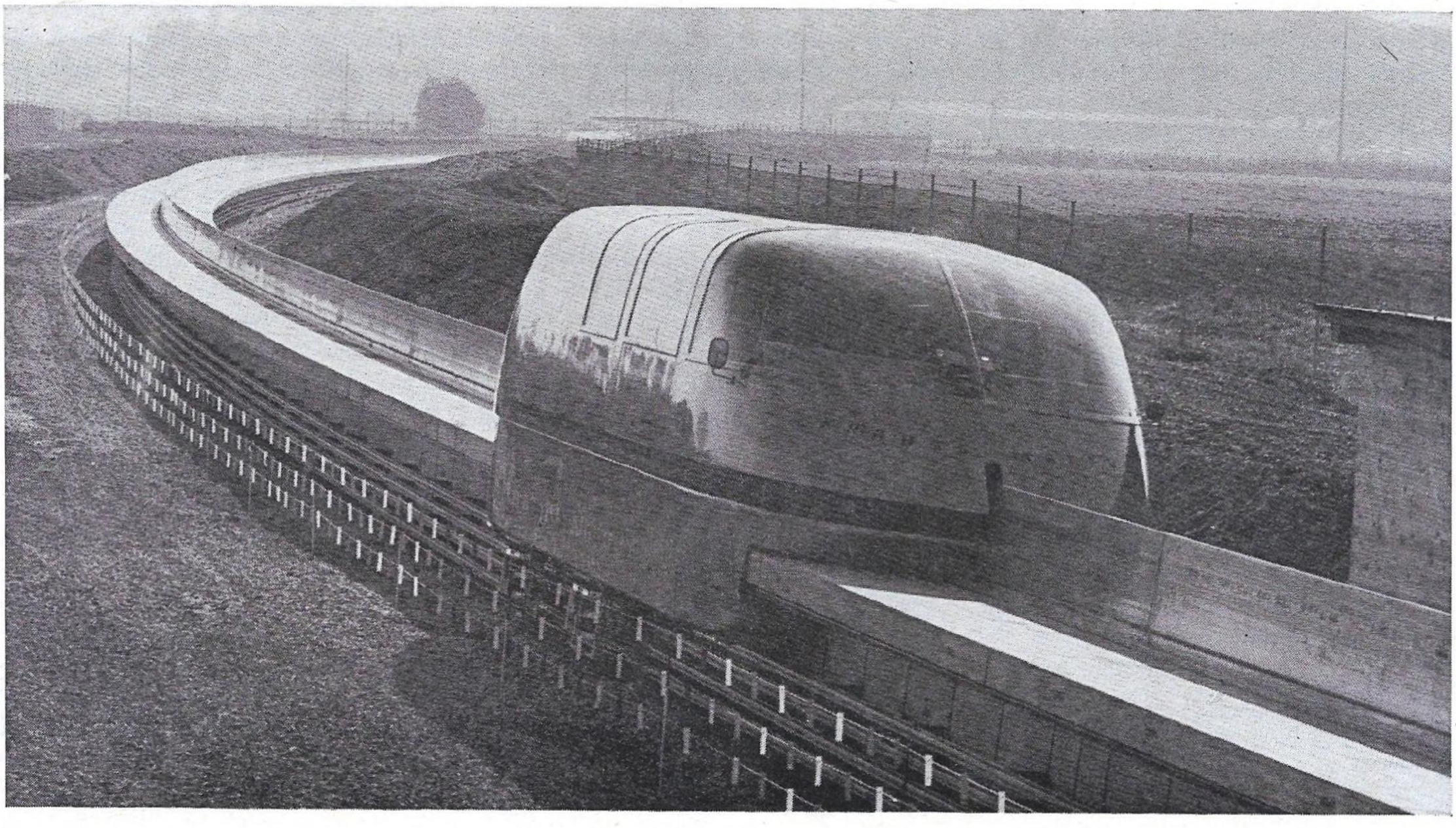
Electromagnetic Flight

The future of high-speed ground transportation may well lie not with wheeled trains but with vehicles that "fly" a foot or so above a guideway, lifted and propelled by electromagnetic forces

by Henry H. Kolm and Richard D. Thornton

Public transportation employing vehicles with wheels appears to be incapable of speeds much above those attained now by technologically advanced railroads. Since a number of valuable purposes would be served by ground transportation at higher speeds, various alternatives to the wheel are being investigated in Germany, Japan, the United Kingdom, Canada and the U.S. Among the alternatives are air-cushioned transport, attractive magnetic levitation and repulsive magnetic levitation. In these studies it is becoming increasingly clear that the future in high-speed ground transportation belongs to vehicles that "fly" about a foot above metal guideways, being supported, guided and propelled by electromagnetic forces. With the technology available today, such systems could operate in the range



ELECTROMAGNETIC VEHICLE developed by a German consortium is operated on a test track. The vehicle runs about one centimeter above the guideway, employing the form of magnetic levitation termed attractive levitation. It is propelled by a linear induction motor that straddles the vertical aluminum reaction rail. Car shown is a test vehicle carrying passengers and instruments.

of speed from 200 to 300 miles per hour, serving certain corridors (Boston-Washington, San Diego–Los Angeles–San Francisco, Houston-Dallas and others) where the density of traffic is already sufficient to bear the cost. Eventually, as the technology improves and demand increases, such systems could span continents, operating in partly evacuated tunnels and moving at speeds limited in theory only by the inevitable curvature of their path. Electromagnetic flight holds the promise of being a juncture in transportation history comparable to the advent of the wheel, the automobile and the airplane.

Like other transportation systems, electromagnetic flight must evolve considerably before reaching a commercial scale. The course of its evolution depends as much on the socioeconomic climate and on national commitments as it does on scientific and technological progress. Public understanding of the issues and problems involved is vital. We therefore undertake here to review both the historical and the technical aspects of the subject.

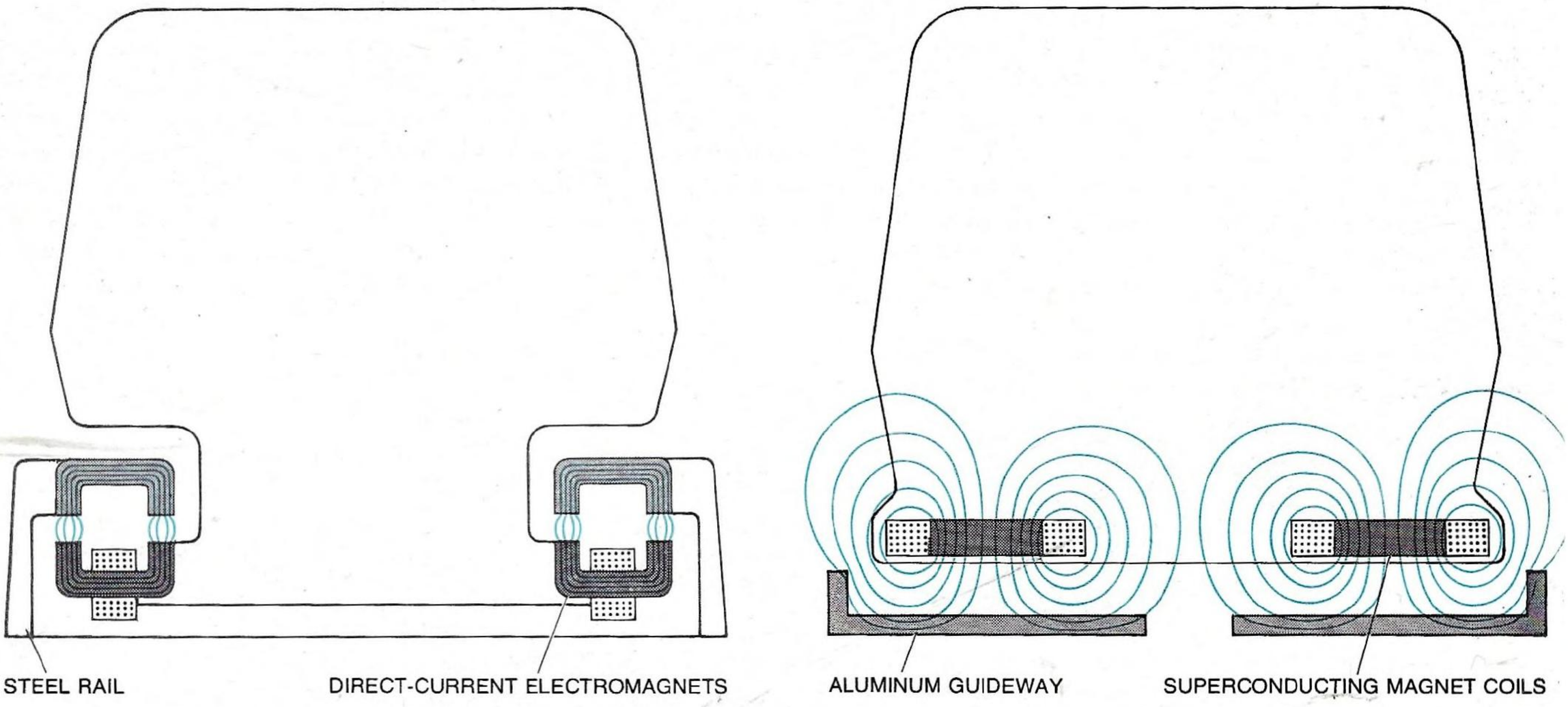
The first stage of the evolution began in the early 1960's with the realization by people concerned with ground transportation that fundamental innovations in technology were needed. Traffic on the highways and airways of several high-density corridors in the world was approaching saturation. The Japanese National Railways had just demonstrated the practical limits of conventional trains, finding that the traction and centrifugal strength of wheels and the frictional heating of pantograph current-collectors meant that such a train could not be operated regularly at a speed of more than about 200 miles per hour. In fact, the New Tokaida Line was unable to achieve day-to-day operation above 135 miles per hour, notwithstanding nightly realignment of the all-welded tracks and readjustment of the meticulously designed catenary cable. As a result of these findings many people started looking for alternatives to the wheel. From these efforts emerged what can be called the first generation of wheelless trains.

At the time the tracked air-cushion vehicle appeared to be the most logical alternative. Large untracked hovercraft had been built, and the technology of air cushions seemed to be well in hand. The British developed their Hovertrain, the French their Aerotrain and the U.S. Federal Railroad Administration its TACV. For various reasons, however, the development of air-cushion vehicles has not met with much success. The Hovertrain was officially terminated last February, construction of the Aerotrain has been postponed repeatedly and the TACV is now viewed primarily as a source of valuable information and by-products, notably the high-speed test facility built at Pueblo, Colo., as part of the program.

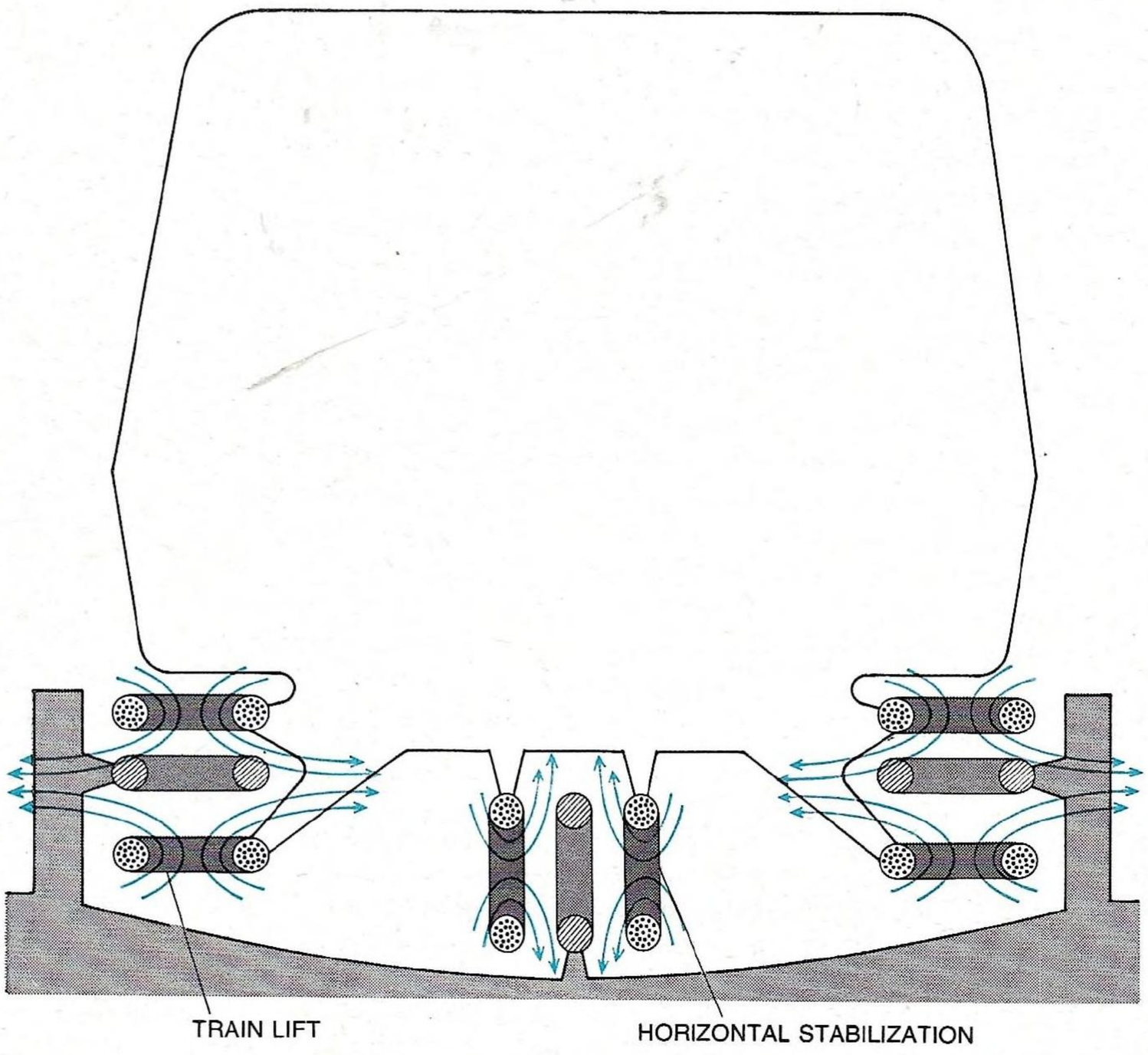
Magnetic levitation was also a well-known concept in 1965, the earliest proposal on record having been made in 1912 by the French engineer Émile Bachelet. Some of the early schemes were economically impractical, such as those that involved paving a guideway with permanent magnets to repel an oppositely magnetized vehicle. Others required supporting technology that existed but was unknown or at least untried in the context of railroad engineering.

Two entirely different approaches to magnetic levitation (which is often shortened to "maglev") are being pursued. One is attractive (or ferromagnetic) levitation, which involves vehicle-borne electromagnets that cling without contact to the underside of a suitably shaped steel rail or channel [*see illustration at left below*]. The system is inherently unstable because the attractive force increases as the magnet in the vehicle approaches the rail, requiring artificial stabilization by means of high-power, solid-state electronic feedback systems that regulate the current of the magnet so as to prevent contact.

In such a system the amount of continuous power required to maintain lift remains quite reasonable (about two kilowatts per ton) up to clearance gaps of about two centimeters, although the peak power required to adjust the lift force increases rapidly as the amplitude and frequency of the required adjustments increase. A system employing attractive magnetic levitation therefore must have accurately aligned guide rails if high speeds are to be achieved. The exact trade-off between cost and speed



ATTRACTIVE AND REPULSIVE LEVITATION are portrayed. Attractive levitation (*left*) is based on electromagnets that cling without contact to the underside of a steel rail. Repulsive levitation (*right*) is based on the repulsive force experienced by a magnet moving above a conducting, nonmagnetic surface. With superconducting magnets, which carry large persistent currents if kept at a low temperature, repulsive levitation can lift a vehicle about a foot above the guideway. Magnetic fields are depicted in color.



NULL-FLUX SYSTEM was proposed by James Powell and Robert Danby of the Brookhaven National Laboratory. Two opposing coils on the vehicle carry a persistent superconducting current and straddle a single track loop. The system can also work with a single vehicle coil flanked by two track loops connected in opposition. This was the first scheme for repulsive levitation of high-speed transportation vehicles by superconducting magnets.

speeds. The superconducting levitation magnets provide magnetic fields that are not only very intense but also of large volume and can be efficiently coupled to fixed stator windings in the guideway, even at clearance gaps of about a foot. The increase in rotor current made possible by superconductivity opens the way to a reduction of the stator current and so to much simpler stator structures than were considered previously. As for the problem of synchronization, we have demonstrated at the Francis Bitter National Magnet Laboratory at the Massachusetts Institute of Technology that it can be solved easily by transmitting position information from the vehicle to wayside power-control units, which is much simpler than transmitting power from wayside units to a moving vehicle.

The development of magnetic-levitation systems has progressed quite far in Germany and Japan. In Germany two industrial teams (Krauss-Maffei and Messerschmitt-Bölkow-Blohm) have independently developed ferromagnetically levitated vehicles propelled by linear induction motors. By 1971 each consortium had completed a test track and an instrumented, passenger-carrying test vehicle. Both systems operate at a clearance of about one centimeter, with levitation magnets riding below an overhanging steel rail. A separate linear induction motor straddles a vertical aluminum reaction rail. Although the alignment requirements make for expensive construction, both systems represent serious competition for wheeled trains.

A third German consortium (Siemens, AEG-Telefunken and Brown, Boveri & Cie.) is pursuing a longer-range project involving repulsive superconducting levitation. The team has almost completed a circular test track 280 meters in diameter and is planning a 20-kilometer straight test section. All the German projects have had assistance from government ministries.

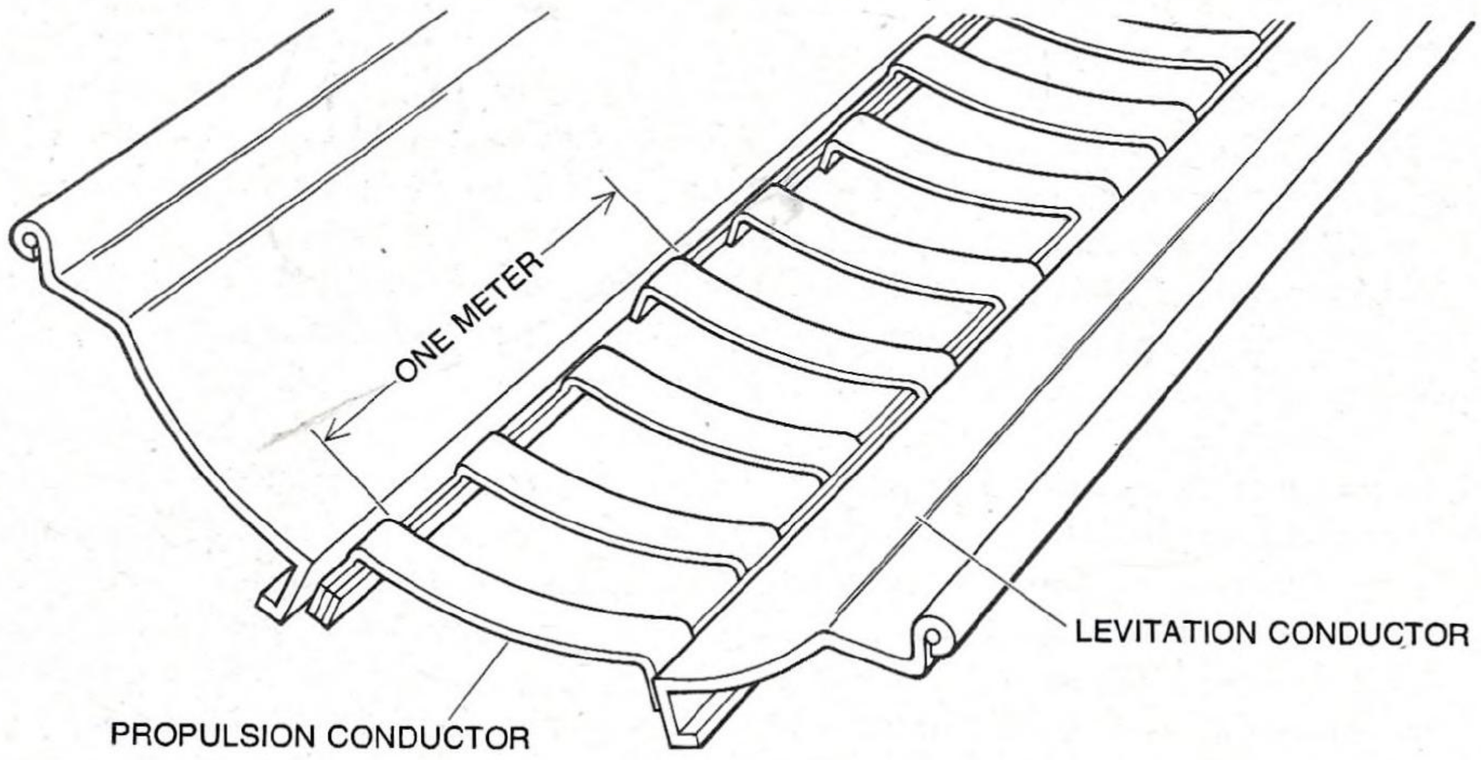
In Japan the Japanese National Railways (in collaboration with all the major electrical industries) decided after exhaustive study to adopt repulsive superconducting levitation with a small gap and with propulsion by linear induction motors. The plan was later modified by increasing the clearance gap to several inches and adopting linear-synchronous-motor propulsion. According to the schedule, a half-scale test vehicle will operate on a seven-kilometer test track by next year.

To complete our account of the fir era of magnetic levitation we shoul mention a ferromagnetic attractive sy tem being developed privately by Rol Industries, Inc., of California. It diffe radically from the two German systen in that the lift-magnet structure wor on alternating current and is employe not only to lift but also to produce li ear-induction-motor propulsion. The sy tem has been demonstrated successfu at moderate speeds and may eventua provide the winning technology for narrow-gap system.

The first proposal for the repulsiv levitation of vehicles by supercon ducting magnets was published in 196 by James Powell and Robert Danb of the Brookhaven National Laboratory As physicists they were concerned wit the design of magnets for confining, fo cusing and bending beams of high-en ergy charged particles. Although supe conducting magnets were then bein used by physicists, the broader scientifi community had neither an interest in n the money for applications of supercon ductors to transportation, and the trans portation community viewed the propo al with more amusement than interes Powell and Danby developed the con cept in their spare time, with support (a they put it) from their wives.

Their first scheme involved a supe conducting guideway, but they later re fined what has come to be known as th "null flux" scheme, which is the basis o the system being implemented at fu scale in Germany. Powell and Danb found that a significant reduction in dra can be achieved by arranging the guide way loops so as to achieve an extremel high field gradient, that is, a field inte sity that changes drastically with chang es in position. The feat is accomplishe by having two opposing guideway loop flanking a single coil on the vehicle o conversely, two opposing vehicle coil flanking a single guideway loop [*see il lustration on this page*]. A null-flux sus pension therefore provides not only high lift-to-drag ratio but also stron restoring forces, or great stiffness. Un fortunately the system is so stiff tha alignment of the guideway again be comes critical and a secondary suspen sion is essential. The secondary suspen sion creates added weight, aerodynami drag and loss of power, which cancel much of the advantage in efficiency.

By 1969 several theoretical studies o inductive levitation had been published Two of them are particularly noteworthy in the context of this article. C. A. Gu derjahn, S. L. Wipf and several co-work



MAGNEPLANE GUIDEWAY consists of meandering aluminum coils that serve as linear stators and are flanked by passive aluminum troughs that allow vehicle to roll into a coordinated bank angle in curves. Strong superconducting levitation coils on vehicle serve as rotor of a synchronous motor. Most of aluminum has both electrical and structural purposes.

we have managed to develop a guideway design in which most of the aluminum serves both structural and electrical purposes [*see illustration above*].

Detailed studies indicate that the cost of the guideway is comparable to that of any other projected high-speed system and that it is not in any way dominated by the fact that the propulsion system forms an integral part of the guideway structure. The linear synchronous motor thus offers a formidable combination of advantages: it eliminates the massive onboard equipment required for propulsion by the linear induction motor, along with the separate reaction rail, the narrow clearance gap and the need for a sliding power-pickup system. The reduced weight of the vehicle leads in turn to reduced costs for the guideway (a particularly significant factor in elevated construction) and reduced power requirements.

Synchronization of the linear synchronous motor is accomplished quite easily by transmitting position information from the vehicle to the wayside power-control units, which are positioned at intervals of about 10 miles. These units contain transformers and computers that actuate transformers and solid-state switches positioned at one-mile intervals along the guideway. The phase, frequency and amplitude of the multiphase propulsion current are automatically adjusted to maintain synchronous acceleration, deceleration and cruise. The system thus substitutes information transmission for power transmission.

Two additional advantages are inherent in the linear-synchronous-motor approach. First, positive control of each vehicle by wayside units connected to a central computer allows safe operation at the levels of traffic density and vehicle headway that are absolutely essential for the economic feasibility of any high-speed ground transportation system. Second, the system eliminates the shocks and lurches of wheeled systems and small-gap suspensions, thereby providing a comfortable ride that can be expected to make the system highly acceptable to passengers. The system does sustain slow oscillations (having a period of about one second) that are inherently underdamped and that cannot be damped completely by any known passive technique. We have found that the propulsion-control system provides a simple means for actively damping such oscillations. By adjusting the phase position of the propulsion on the basis of accelerometers carried on the vehicle, heave disturbances of considerable vertical force can be damped. Since the nonlinear repulsive force and the circular geometry couple heave with pitch, sway, roll and yaw, these other motions can also be reduced.

In sum, the magneplane can be likened to a magnetic surfboard riding the forward slope of a traveling magnetic wave whose speed of travel and height are constantly adjusted to keep the surfboard in smooth motion. The controlled "surf" also damps heave motions of the vehicle, thereby providing active control of the ride without the need for springs or shock absorbers, neither of which are very practical at high speeds.

The initial capacity of the guideway would be 6,000 passengers per hour in each direction. It could probably be doubled as the technology matures. The magneplane concept differs fundamentally from conventional railroad thinking: instead of providing 50 mega of wayside power capacity to pro 1,000-passenger train every hour, i vides five megawatts of wayside p to propel a lightweight 100-pass vehicle every minute. The achieve is made possible by off-line loadin automatic, positive control of all m of the vehicle. Conventional rai are basically linear; applied t Northeast Corridor, for example, can provide 10-stop trains at hou half-hourly intervals. Magneplan the other hand, could serve doz stations connected by branch loops vehicles operating at one-minute vals and none of them making mor one or two stops between Bosto Washington.

Initial development of the m plane at our laboratory was supp by funds from the Sloan Found The effort was later joined by the Systems division of the Avco Co tion, the Raytheon Equipment D and United Engineers and Constru Inc., with material support by th Company and ALCOA. In this team of investigators with skills merous disciplines was brought t on the project. From M.I.T. the participants are Yukikazu Iwasa born C. Brown, Joel H. Schultz an ert C. Wallace. The results have l influence on thinking about ma levitation and have also led to st by the new division for Researc plied to National Needs of the Na Science Foundation. In addition tailed studies of the need for a ful system, the work has progressed construction of a fully operational model magneplane system that wi be demonstrated publicly.

During this time the Federal Ra Administration has been grapplin the problem of obtaining a factua for a policy decision on the tech of high-speed ground transpor Having committed some $30 mil the development of tracked air-c vehicles propelled by linear ind motors, the agency was reluctant Congress to support a major progr magnetic levitation simply becaus many and Japan had done so. Be 1971 and early 1973 the agency p ed money for analytical studies o netic levitation by the Ford Motor pany and the Stanford Research tute; the studies confirmed the pr feasibility of both attractive and sive levitation and identified the tial requirements and problems i areas.

The Federal Railroad Adminis

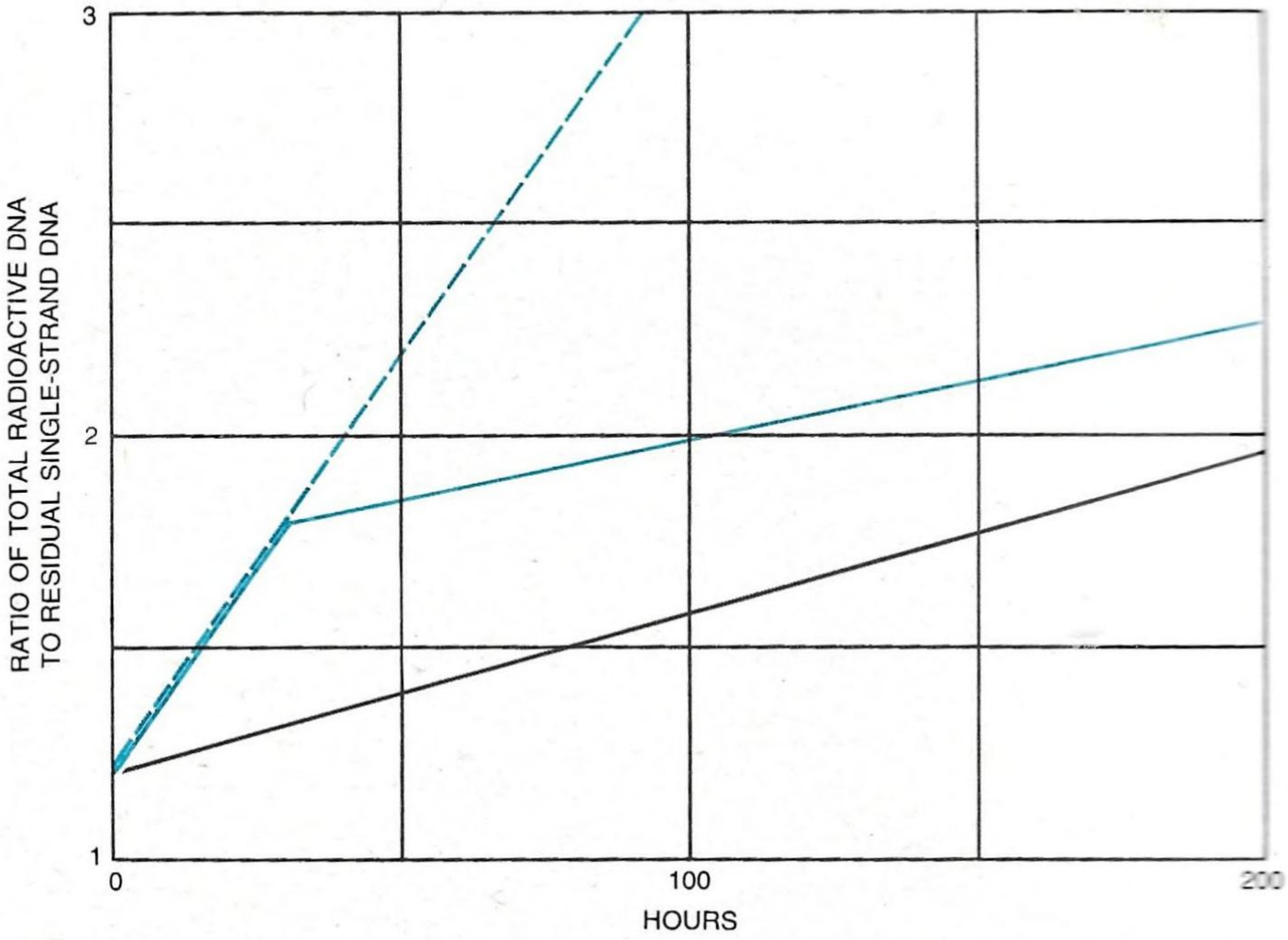
The incidence of nasopharyngeal carcinoma is extraordinarily high in certain populations. Virtually all the known cases are seen in Chinese from South China, Malaysia and Singapore. H. C. Ho of the Queen Elizabeth Hospital in Hong Kong has assembled data suggesting that the lifetime incidence in Hong Kong may be as high as one in 200. Among the "boat people" of Hong Kong the incidence is even higher. People of Chinese descent who are born in the U.S. show a lower incidence of the disease but still one that is higher than the incidence in the general population. As with Burkitt's lymphoma, nasopharyngeal carcinoma is found throughout the Western world at low incidence. Even though the data are still inconclusive, they do suggest that some cultural factor may be involved in addition to a possible viral one.

Guy de-Thé of the World Health Organization's International Agency for Research on Cancer in Lyon has grown cells from nasopharyngeal-carcinoma-tumor tissue in suspension culture. This culture produces virus particles that appear to be identical with those of Burkitt's lymphoma, but further studies are needed.

The genital form of herpes simplex (Type 2) is found in sores or reddened spots on the cervix and vaginal walls of infected women and on the penis and in the genital tract of men. Ysolina M. Centifanto and her colleagues at the University of Florida College of Medicine have found that 15 percent of men of all ages from 15 years on harbor Type 2 herpes simplex in the genital tract, for the most part in the prostate and vas deferens. The virus is seldom isolated from the female genital tract; women tend to have acute, short-lived and recurrent herpes virus genital infections. It may be that many men harbor the virus without developing the symptoms of infection but are capable of transmitting it.

André J. Nahmias of the Emory University School of Medicine has been able to establish a convincing association between the Type 2 herpes-simplex virus and cancer of the cervix, and Centifanto has described one case in which the herpes virus could be seen in the cells of tissue from cancer of the prostate. An intriguing bit of evidence comes from a study undertaken by Niza Frenkel and her colleagues at the University of Chicago, who were working with tumor tissue supplied by Nahmias. The study involved hybridization experiments with DNA from cervical-carcinoma cells [*see illustration on this page*]. They found that some DNA from Type 2 herpes-simplex virus is indeed present in these cells, but that 60 percent of the viral DNA molecule is missing. The missing portion could explain why neither the complete virus nor viral antigens can be isolated from the tumor tissue. The portion of the viral DNA that is present could become attached to the normal cell DNA and could be responsible for maintaining the cell in a malignant state. In addition the missing part would be required for the production of the complete infectious virus.

The recent discovery by Luis V. Melendez of the New England Regional Primate Research Center that the New World squirrel monkey harbors a herpes virus capable of inducing tumors in owl monkeys and marmosets is highly significant. For the first time it is possible to conduct cancer-transmission experiments on animals much more closely related to man than frogs and chickens. What is even more promising is that the resulting tumors in monkeys are similar to herpes-associated tumors in man. Unlike cultured cells infected with the Epstein-Barr virus, the cells harboring the squirrel-monkey virus (called herpes saimiri) grow on the surface of the culture vessel. This makes it easier to produce large amounts of the virus for investigation or for vaccine manufacture.



RATE OF HYBRIDIZATION is determined by measuring the amount of radioactivity in the final hybridization product over a period of time. The measurements are converted so that the vertical axis is a function of the increasing proportion of double-strand radioactive DNA present. If the cell DNA contained no viral DNA segments, the rate would be what is shown by the black curve. If the cell DNA contained complete copies of the viral DNA, the rate would rise constantly, as is shown by the broken colored curve. In a recent hybridization experiment with human cervical-carcinoma cells and herpes virus DNA, Niza Frenkel and her colleagues at the University of Chicago found that the rate rose but then dropped off, as shown by the solid colored curve. From these results they calculated that only about 40 percent of complete-virus DNA was present in cervical-carcinoma-cell DNA.

Quite recently two groups of investigators showed that the Epstein-Barr virus can induce lymphoid tumors in monkeys. One of these workers was Epstein himself, who used the virus to induce a tumor in an owl monkey. Thomas C. Shope, D. C. DeChairo and I. George Miller, Jr., of the Yale University School of Medicine induced malignant lymphomas in four cotton-top marmosets. Since such experiments cannot be performed in man, this is about as far as we can go in showing directly that a virus from human cancer is in fact a cancer-causing virus, which is a different matter from finding a virus in a tumor.

Thus the prospect is good that it will eventually be demonstrated beyond a reasonable doubt that herpes viruses can cause some forms of cancer in man. Nonetheless, an alternative explanation cannot be ignored. It is that herpes viruses are present in some human tumors merely as passengers and are not involved in the development of the tumor itself. If any human cancers are shown to be caused by a virus, there is hope that those forms of cancer can be eliminated, or at least much reduced in frequency, by the development of suitable vaccines or by finding ways to interrupt the primary routes of infection.

throwers and archers, received little recognition in the days when only hand-to-hand combat between armored warriors was considered honorable. Pictorial representations of hoplites (and even of archers and javelin-throwers) are common enough, but slingers are seldom seen.

Lightly armed troops nevertheless played a major role in warfare during classical Greek times. To them was given the initiation of battle. The shower of javelins, arrows and slingstones they let fly might open a breach in the opposing ranks; at the least it would expose weak points in the enemy formation that the advancing heavy infantry could exploit. Moreover, if the advance was unsuccessful, the lightly armed troops were available to cover the heavy infantry's retreat. An army that entered battle without peltasts was as good as defeated.

We have a detailed account of the fate of just such an army; it had been deprived overnight of almost all its lightly armed troops. This was the force of 10,000 Greek heavy infantrymen that was the backbone of a much larger army seeking to overthrow the king of Persia in 401 B.C. After the pretender to the throne who led them had fallen at the Battle of Cunaxa, the pretender's native forces fled and the Greeks were left alone. The Athenian Xenophon undertook to lead the 10,000 Greek infantrymen to safety, but on their first day's march they were so plagued by small numbers of enemy cavalrymen, archers and slingers that they could travel only some 25 stadia: less than three miles. That night Xenophon declared to his captains: "We need slingers ourselves at once, and horsemen also."

"Now, I am told," Xenophon continued, "that there are Rhodians in our army, that most of them understand the use of the sling, and that their missile carries no less than twice as far as those from the Persian slings. For the latter have only a short range because the stones that are used in them are as large as the hand can hold; the Rhodians, however, are versed also in the art of slinging leaden missiles."

STARTING POSITION, with sling poised above the head, is seen in this sculpture of a Neo-Hittite slinger from Tell Halaf in Syria, executed in the ninth or eighth century B.C.

Xenophon and his colleagues soon recruited from the ranks 200 slingers and a cavalry squadron of 50 men mounted on packhorses. The addition of these lightly armed forces to a body of 200 Cretan archers among the 10,000 enabled the Greeks thereafter to give a good account of themselves against the pursuing Persians. The Cretan archers' range was not the equal of the Persian archers', but the Rhodian slingers, Xenophon noted, "carried farther with their missiles than the Persians, farther even than the Persian bowmen." Considering that the archers of Persia were then regarded as the best in the world, his statement speaks well for the range of the Greek slingers.

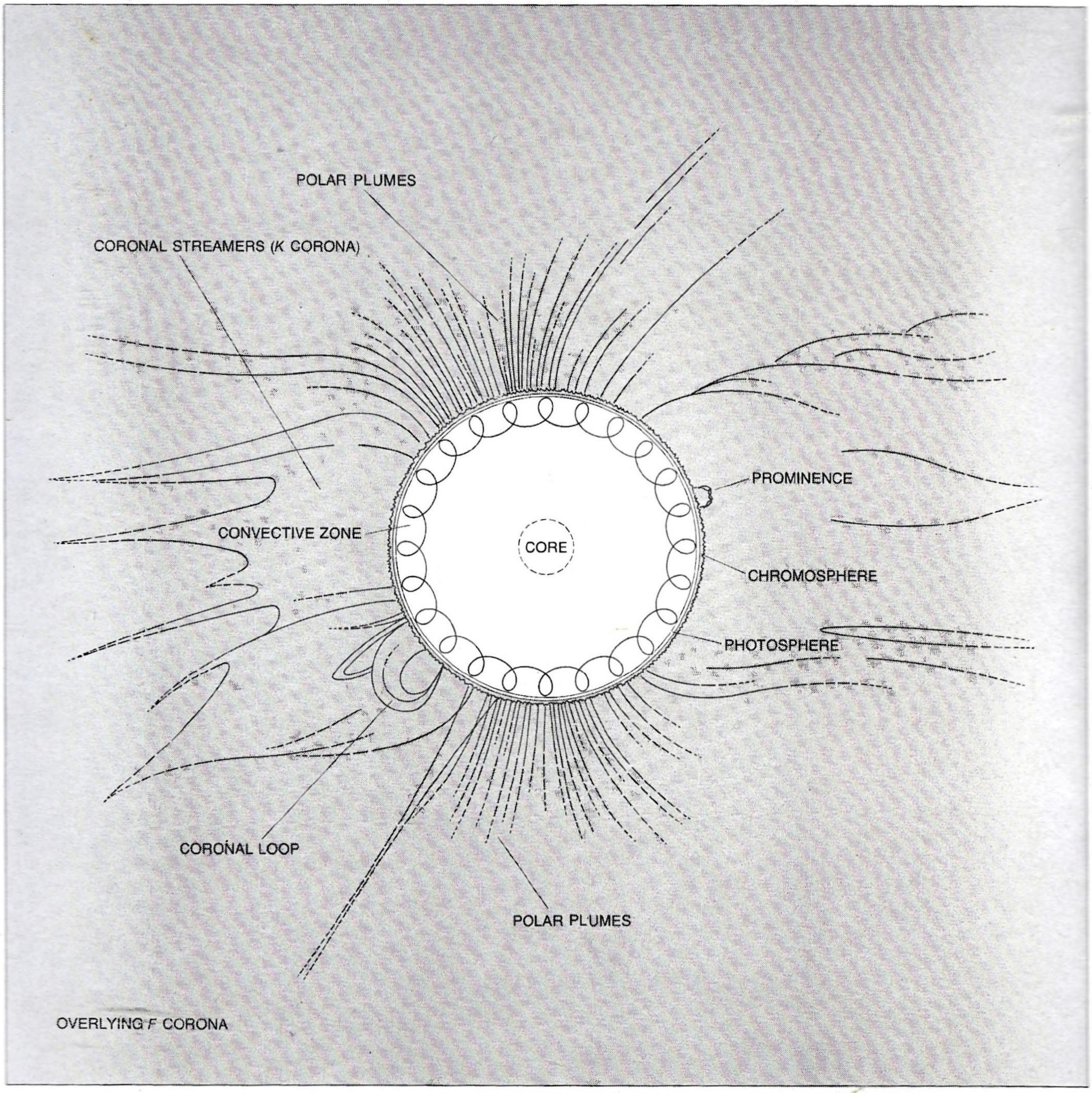
Exactly how do the sling and the bow compare in range? The Roman military commentator Vegetius, writing in about A.D. 400, recommended target practice with the bow at a range of 180 meters. Even a modern sporting bow with a 45-pound pull can propel its arrow little more than 200 meters. With a long, light "flight arrow" and a bow with a 60-pound pull an archer trying for distance might achieve a range approaching 275 meters. By way of comparison I asked some young men in eastern Turkey to sling ordinary pebbles for me. In five out of 11 trials the pebbles struck beyond a mark placed 200 meters away, and the three best casts fell between 230 and 240 meters away. None of the young men appeared to be a skilled slinger; at least none had a sling in his possession at the time. Moreover, the missiles were pebbles selected at random rather than the carefully shaped stone, clay or lead missiles launched by slingers in Greek and Roman times. On the basis of Xenophon's comment alone it seems probable that a slinger casting lead missiles could attain a range in excess of 400 meters.

The sling I have been discussing is the flexible hand sling (*funda* in Latin). There is a second kind of sling: the staff sling (*fustibalus* in Latin). The hand sling can be no more elaborate than a strap three feet or so in length and an inch or

sorbed within the photosphere. This component of the corona is called the *K* corona, from the German *Kontinuum*.

At about two solar radii the *K* corona is less dominant, and radiation is added by sunlight scattered by the dust that is distributed through interplanetary space. In its spectrum this second component of the corona shows the dark Fraunhofer lines and is therefore called the *F* corona. The *K* corona continues out into space along with the *F* corona, although it gets fainter with increasing distance from the sun. It extends even past the orbit of the earth, although at such distances it is of course extremely thin. Thermal radiation from the dust has been observed in the far-infrared.

The third major component of the light of the corona is revealed by emission lines in the spectrum of highly ionized atoms near the sun: atoms stripped of as many as half of their constituent electrons. Although this radiation is very weak and makes a negligible contribution to the total intensity of the corona, it yields detailed information



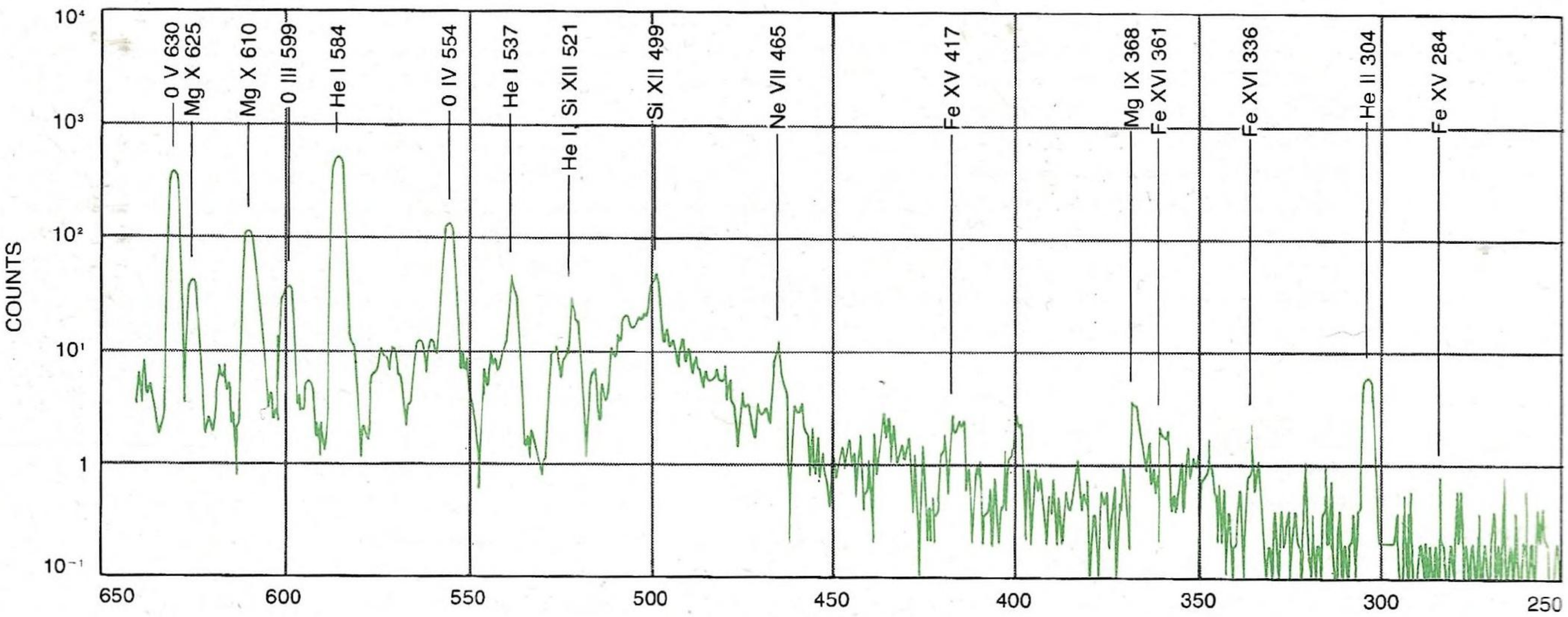
STRUCTURE OF THE SUN and the corona is summarized in this cross-sectional diagram. Energy from thermonuclear reactions in the core makes its way gradually to the sun's exterior layers. Most of the visible light received on the earth comes from the photosphere. Just under the photosphere is the convective zone. Shock waves from the convective zone carry energy up into the chromosphere and the corona. The temperature of the sun is at a minimum in the photosphere and lower chromosphere; the shock waves cause the temperature to rise through the upper chromosphere and the corona until it reaches some two million degrees Kelvin in the corona. From the corona the solar wind expands into interplanetary space. The visible corona has three major components. The first is the *K* corona: light scattered by the electrons in the gas surrounding the sun. The second is the *F* corona: light scattered by the interplanetary dust between the sun and the earth. The radiation of third component is emitted by highly ionized atoms near the sun.

the corona as shock waves from lower levels of the sun, probably from below the photosphere in the convective zone [*see illustration on page 70*]. The temperature rises throughout the chromosphere and then jumps rapidly a million degrees in the few thousand kilometers immediately above the chromosphere. The exact mechanism by which the energy is transported to the corona and then dissipated is a matter of intensive research and some controversy.

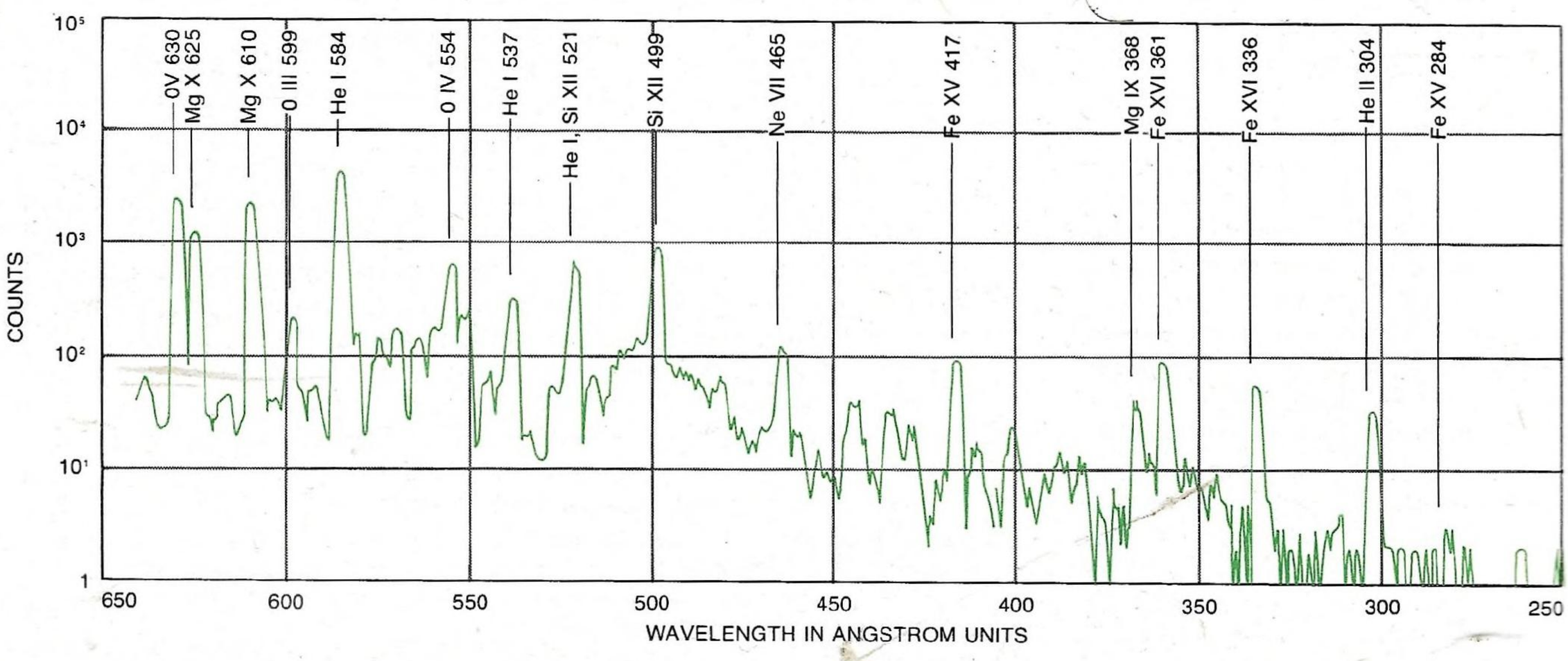
The emission lines from the highly ionized atoms make it possible to detect the corona even without a solar eclipse. Ground-based observations of these lines can be made from a few ideal sites. In principle the requirements for such observations are simple: the observer must have a very clean sky and very clean optics. In practice, however, these requirements are difficult to meet, and it was a major achievement when Bernard Lyot of France succeeded in constructing a coronagraph in the 1930's.

A coronagraph is usually a refracting telescope because microscopic pits in the mirrors of a reflecting telescope scatter too much light. At the focus of the primary lens of the telescope an image of the sun is formed on a small occulting disk that is exactly the size of the image of the photosphere. With the intense photospheric light blocked, there is hope of detecting the corona. The image of the corona is refocused and sent through filters that select the desired wavelengths for observation. Observations are usually made through filters that isolate the wavelengths around a coronal emission line, since such lines are brighter than the continuous spectrum.

Making a successful coronagraph is still something of an art. That fact is captured in an article on coronagraphs written by John W. Evans, director of the Sacramento Peak Observatory in Sunspot, N.M., in which he describes



SPECTRUM OF CORONA OVER QUIET REGION of the sun from 650 to 250 angstroms was measured from the Harvard College Observatory spectrometer aboard OSO-VI. From 504 to 470 angstroms the continuous spectrum of helium is visible as a gradual rise in intensity. *Mg* is magnesium, *He* is helium and *Ne* is neon. The principal investigators were Andrea K. Dupree, Martin C. E. Huber, Robert W. Noyes, William H. Parkinson, Edmond M. Reeves and George L. Withbroe of Harvard College Observatory.



SPECTRUM OF CORONA OVER ACTIVE REGION of the sun was measured from the Harvard spectrometer on OSO-VI in an area of sunspots and flares. The entire spectrum is about 10 times stronger than the quiet-region one at top. Also certain spectral lines, such as the line of nine-times-ionized magnesium at 625 angstroms, are enhanced with respect to the background continuous spectrum.

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detected out to about 80 solar radii. Presumably it is merely an extension of the *F* corona.

One set of data that helps to bridge the gap comes from the unmanned lunar vehicles of the Surveyor series. On the moon's airless surface there is obviously no atmospheric scattering of light. The corona simply rises each morning before the sun's disk and sets each evening after it. J. David Bohlin of the Naval Research Laboratory analyzed some of the data from *Surveyor 6* and *Surveyor 7*. He could follow one coronal streamer detected by *Surveyor 7* out to 22 solar radii.

Measurements at radio wavelengths can also be utilized to find the density of electrons in the outer corona. The corona tends to displace the apparent radio position of the Crab Nebula or quasars as they pass behind it. It also changes the apparent period of the radio signal from pulsars. Both types of change depend on the total density of electrons in the line of sight.

The structure of the corona varies strikingly from one eclipse to another. Its form has long been linked with the cycle of solar activity associated with the 11-year sunspot cycle. The shape of the corona is quite irregular when the number of sunspots is at a minimum (as

LOOPS OF IONIZED PARTICLES streaming away from the sun's surface more than 25,000 miles into space are shown in an electronically recorded image made by a scanning ultraviolet spectroheliometer aboard the manned satellite Skylab. The instrument is one of the solar physics experiments in the Apollo Telescope Mount and is the project of a group from the Harvard College Observatory led by Reeves. The Skylab spectroheliometer has a resolution some 30 times greater than that of similar instruments flown on the Orbiting Solar Observatories, revealing these distinct loops in the wavelength of 14-times-ionized iron at 417 angstroms. With the ultraviolet measurements very accurate temperatures can be determined for levels within the sun's atmosphere. Such measurements are made twice a day during both the manned and the unmanned periods of the Skylab mission.

stant to within a few percent in metal-to-metal contact, even if the load is increased by ten- to a hundredfold. Slide a steel ball over an acrylic plastic surface, though, and Leonardo's empirical approximation is found wanting: the "coefficient" is halved for a load increased sixteenfold. No more is friction proportional to load.

Why? Bowden put it crisply: "Putting two solids together is rather like turning Switzerland upside down and standing it on Austria—the area of intimate contact will be small." Those Alpine profiles are made visible nowadays in three dimensions by the scanning electron microscope, by viewing oblique sections with the optical microscope for vertical exaggeration or electronically by phonograph-pickup techniques. All these methods are exhibited here in photographs that complement the text.

The low-contact area is confirmed by electrical-resistivity measurements, allowing with some difficulty for the layers of oxide and adsorbed gases that dominate "clean" metal surfaces in the air ocean in which we engineering fishes must build. (At high loads the oxide films break down, the contact becomes a good conductor and the coefficient of friction can triple.) The load is borne on "the tips of the surface asperities," and the area of actual contact is tiny. The peaks deform permanently (they feel a high load pressure, of course) until the load is carried by a contact area big enough to support it. That value depends on the material; for mild steel it is some 10 tons per square centimeter.

Slide a heavy toolbox across a steel plate and the load is in fact supported by a contact area of deformed steel no bigger than a comma printed on this page. That area will adjust its size, independent of the size of the bodies, and stay pretty closely proportional to the load; the shape and the number of the contact peaks make little difference. For plastic materials the area adjustments are in fact viscous flows and hence time-dependent; the coefficient therefore varies with speed as well as load.

Friction force between clean metal surfaces is then mainly the force required to shear the friction junctions that form by the cold-welding of heavily loaded peaks. That shear force obeys the old laws of Leonardo, and it is plainly sensitive to grease films and to surface changes that affect the nature of the junctions. The transfer of metal, even under small load and slow motions at room temperature, rather hard to accept at first, is demonstrated by direct autoradiographs. A slider of radioactive lead leaves tiny fragments behind, and these can photograph themselves if an emulsion is left in contact with the track of the slider.

Wear always accompanies friction. Every junction must be sheared, but not every shear transfers material; the junction can fail either at a weld proper or at an oxide-layer film between metal surfaces. For steel on steel perhaps 1 percent of the junctions produce a wear fragment; for polyethylene on steel the "welds" are weak, and only one in 10 million transfers material.

There is a puzzle still. Why do materials not adhere at their friction junctions whenever we put one down on another? The answer is twofold: carry out the experiment with clean, soft metals, such as lead, and they do adhere; this was first described in 1734. At high temperatures the effect is even stronger: metal powders sinter together under pressure. Note, however, that adhesion can only be measured by relaxing the load. The big valleys around the little contact summits are stressed only lightly by the load; they will elastically return to their original forms, to change the shape of the interface and "snap [the weak junctions] apart one by one so that by the time we are ready to measure the adhesion there are practically no junctions left." (The "wringing" of precision gage blocks together, which makes them adhere quite strongly, exploits the adhesion of the grease film present; degreased blocks "wrung" will really adhere, and the expensive steel surfaces will be ruined.)

Bearing metals, ski surfaces, lubricants and their additives, brakes and tires and more topics still are treated in this easily read although imperfectly organized book. Rolling friction turns out to arise from the internal losses that accompany elastic deformation of the surfaces. It is small, and lubrication helps it very little, because few junctions are made and those are merely peeled apart, a process much easier than shearing. Noble metals, such as gold, show a friction coefficient several times higher than metals that form oxide junctions; in a good vacuum heat-cleaned metal surfaces will weld readily. Starting at the contact peaks, the junction grows as the peaks flow and deform; the whole of the surface may become an enormous friction junction. The friction bears little relation to the load; the coefficient may reach 50 or more; the surface is heavily damaged.

In the purity of the vacuum the contact surface is simple, but t
friction are more complex. Tl
narrative of the sophisticatio
monplace experience today
the physicist, and of a vict
won, which would surely hav
Leonardo.

NEUROPHARMACOLOGY AND
by V. G. Longo. W. H
and Company ($6.95). HALL
AND SHAMANISM, edited by
Harner. Oxford University Pr
THE BOTANY AND CHEMISTR
LUCINOGENS, by Richard Eva
and Albert Hofmann. With a
by Heinrich Klüver. Charles
Publisher ($14.75). Strange
real and imaginary, are the
of these three diverse but ir
volumes: Longo, a brief cli
Harner, an anthropological sy
Schultes and Hofmann,
around plant families.

In 1943 Albert Hofmann rc
cycle home at lunchtime from
laboratory where he had been
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frightening. War "classified" l
for several years. Michael Harn
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among others, he "met bird-hea
ple [and] enlisted the services
spirit helpers... to fly through
reaches of the Galaxy." Richa
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premedical student Schultes to
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might help him toward a shar
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tons in the laboratory at the U
of Minnesota. Only Longo, a
pharmacologist with an atlas of
encephalograph records to his
has stayed at home (in Rome) to
his book. (Although his book is s
it treats antipsychotics and tranq
as fully as hallucinogens.)

The fact is that among man
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hundred are important to hum
trition, and some 75 yield sub

Scientists in Search of Their Conscience

Edited by
Anthony R. Michaelis
and
Hugh Harvey

In June 1971 scientists from many countries met in Brussels to attend a symposium on *The Impact of Science on Society*. Their lectures and discussions at this meeting, organized by the European Committee of the Weizmann Institute of Science in Rehovot, Israel, are now available in this collective volume.

The responsibility of scientists for society's use of scientific findings was explored in depth at the Conference. Though no hard-and-fast conclusions were reached, the discussions clearly demonstrate that scientists are becoming aware that they can no longer claim that the pursuit of knowledge is divorced from its use. Yet, to face the responsibility for the application of their work would impair their freedom. The loss of freedom is part of the dilemma of science.

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Science and Synthesis

The international colloquium organized by UNESCO on the tenth anniversary of the deaths within a week of one another—of both **Albert Einstein** and **Teilhard de Chardin,** brought together eminent scholars in a free discussion of the need to effect a synthesis, both of scientific knowledge and of the scientific and philosophical approaches to knowledge.

Contributors:

René Maheu • Ferdinand Gonseth • J. Robert Oppenheimer • Werner Heisenberg • Reverend Dominique Dubarle • Sir Julian Huxley • Giorgio de Santillana • Gerald Holton • B. M. Kedrov • François Le Lionnais • Louis de Broglie • René Poirier • Pierre Auger • Jean Piveteau • Reverend Pierre Leroy

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whose effect is narcotic or hallucinogenic. Among plants used by man for purposes other than food, the opium poppy, the tobacco plant, coca and certain large-flowering tree daturas of the northern Andes are species known only as cultivated plants.

There is clear evidence that religion too lies along this path: the psilocybin of the little Mexican mushrooms is associated with an antique cult of the highland Maya, whose stone icons of the mushroom have been found in widespread Guatemalan digs. One paper associates it with "tender, generous, brotherly feelings." These effects are not particularly noted in laboratory studies, one author dryly remarks. The ecstatic chant of the shaman of northeastern Oaxaca is today inspired by the same psilocybin: "the psychoanalyst listens, whereas the shaman speaks," wrote Claude Lévi-Strauss. Eloquence heals; there, in absolute darkness, is poetic ritual: "Thirteen white lights, says. Thirteen mountains of points, says."

Almost 20 years after LSD, Hofmann tested by self-experiment another alkaloid: d-lysergic acid amide. Structurally close to his old drug, this one was less active by a factor of 50 to 100. It was no novel product of the Sandoz synthesists, however, nor was it derived in any way from ergot fungi. It was there in the seeds of certain Mexican morning glories, seeds described by the early Spanish chroniclers as "held in great veneration," the source of a magic Aztec potion, ololiuqui, used to "communicate with the gods and receive the secret things."

The chief grocery-store hallucinogen is an alkaloid in the spice nutmeg. There is a little evidence for its use in India, both ancient and modern, and it is commonly taken in American prisons. Distortion of time and space, floating and flying sensations, separation of the limbs from the body and occasionally imagery can result from ingestion of a teaspoonful or two of the spice, usually with plenty of unpleasant side effects. Its active principle is uncertain, but the best theories suggest one constituent that the body metabolizes into a compound related to a strictly contemporary folk drug, called STP by its Haight-Ashbury discoverers about 10 years ago. (The name was taken from that of the proprietary oil additive, said to increase the pep and power of automobile engines.) It took a couple of years before Government investigators could buy samples of STP, isolate the drug and test it. It was the synthetic 2-5-methoxy-4-methylamphetamine. The structure of all these substances is broadly related to that of mescaline.

The use of plants in the Americas has always been remarkably varied; we know how much the fields of the Old World gained once the ocean was crossed. But Europe has its hallucinogens too. Harner and Longo (the latter's clinical-textbook style is at this point suddenly illumined with four engravings of witch flight from Goya) both discuss the role of "flying ointment" and various other potions in the ritual and personal experiences of European witches and warlocks. Harner's Jívaro shamans used both *Datura*, yielding scopolamine, like the European plants, and the non-European harmine alkaloids. But the *Datura* is "too strong," they held, for shamanism itself. A shaman must operate socially while under the influence; the *Datura* is apt for the vision quest, the search for supernatural contact, but it induces sleep and muddies the more complex side of ritual behavior. Therefore in Europe there were two distinct phases within the practice of witchcraft: the Esbat, a ritual meeting of adepts without drugs, and the Sabbat, the "orgiastic gathering," which was in fact somnolent and solitary, simply a flight trance under the influence of some *Datura*-rich ointment, with its scopolamine and hyoscyamine.

How does it all happen? We are far from understanding the basis of these remarkable pathologies. Longo's text notes the similarities or antagonisms of the drugs to known transmitter substances in the central nervous system, and considers as well the evidence of electrophysiology. Simple explanations—synchronizing certain systems of brain waves, resemblance to some natural transmitter compound—seem to promise well, but they peter out. The remarkable complex within our head is not yet mapped territory. The more credulous of the 10 anthropologists and fieldworkers who appear in the Harner collection are even tempted by a wondrous anecdote or two to believe that the vine snuff or the mushrooms connect the user with another world, or even with distant earthly lands.

The reader of these related books sees a much more comprehensive unity: the drugs disclose an interior world. Shaman or anthropologist, novelist or organic chemist, witch or neurophysiologist or volunteer, the richness is internal. Let the visual field part and glide, the images turn into color negatives, or bear stripes and edges, and we can see grand snakes and rare tigers, unknown black

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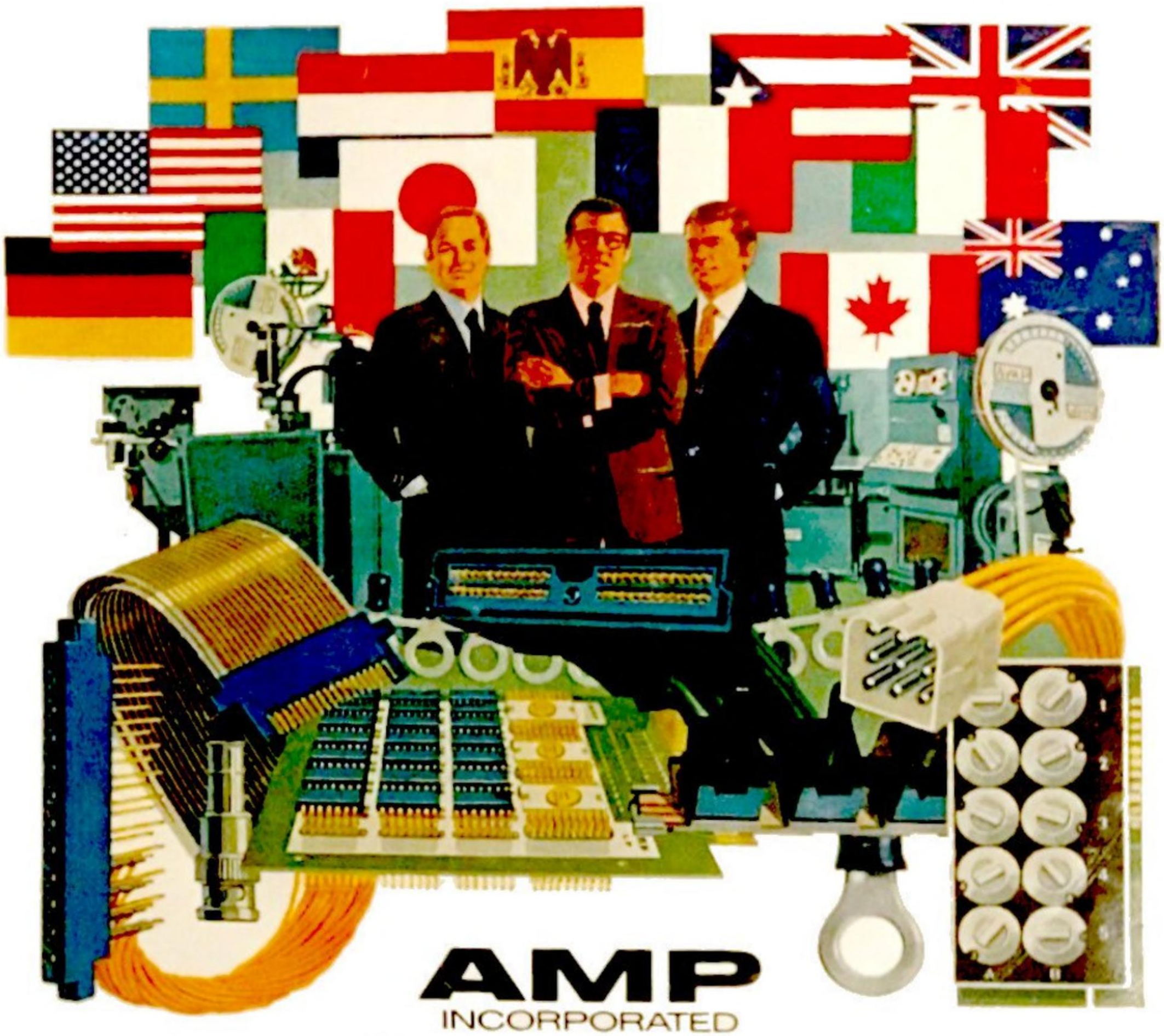

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